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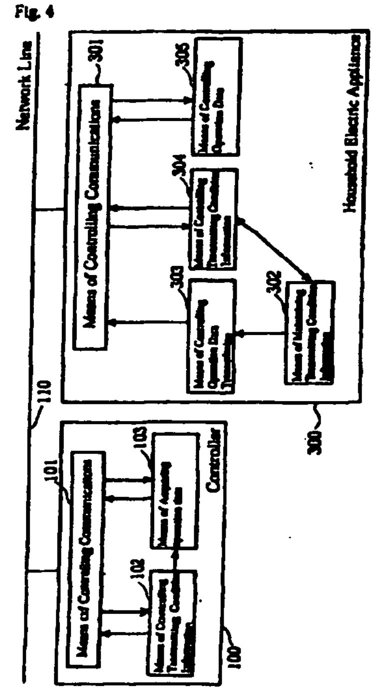
(54) HOUSEHOLD APPLIANCE CONTROL NETWORK SYSTEM

(57) In a control network system of household electric appliances, particularly, an each introduction of a household electric appliance thereto does not cause a change in the means of acquiring operation data by a controller, and the electric power consumption of a controller is made less.

A home network system is simplified and made efficient.

As a means for the above, an accessible device in a common manner to household electric appliances is incorporated into a controller by object processing using communications middlewares, and a device for linked operations is incorporated into household electric appliances. Then, it is noted that each household electric appliance needs a specific kind of another appliance and operation data thereof.

Fig. 4



EP 1 115 263 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to control network systems of household electric appliances. More particularly, the invention relates to exchanges of operation data between household electric appliances provided in home networks and the most appropriate operations in accordance with the data.

BACKGROUND OF THE INVENTION

(General background arts of the present invention)

[0002] In recent years various appliances have been used in houses, buildings, and floors and sections thereof. Accordingly, attempts to acquire more comfortable life, improve operating conditions, save more energy and make operations more efficient have been made by integratedly controlling the appliances under home networks (or home network systems).

[0003] Specifically, for example, air conditioners, refrigerators, fans, solar heaters for bathwater, microwave ovens, hot-water supplies, electric kotatsu, warm air circulators, electric clocks, televisors, illuminators or the like are used in houses. Since time and period when these appliances are used relate greatly therebetween, operation and standby thereof are properly controlled in consideration of conditions such as the time and the period so that more comfortable life, a saving of more energy and the like are intended.

[0004] More specifically, the attempts are as follows:

1) Solar heaters can be frequently used for bathwater in the summer season. Thermostat of hot-water supplies, therefore, does not have to be set to so high temperature in a time slot for bathing so that the bathwater should be set to lower temperature than the winter season.
2) Power level of air conditioners is reduced even in the summer season for an extremely short time for using microwave ovens. Consequently, electric power simultaneously consumed in the whole house can be decreased.
3) Power level and switching of air conditioners in rooms are controlled by detecting the presence of persons therein with sensors.
4) Power level of air conditioners in offices is controlled by sensing the operating conditions of appliances as heating sources in operation therein.
5) Unnecessary illuminators in rooms are switched off in accordance with the time of day and the positions of appliances in operation therein.
6) Illuminators and air conditioners in empty classrooms are switched off at universities.

[0005] In addition, it has been studied and attempted that not merely the switching of appliances is controlled in accordance with seasons and the time of day but also aged people and infants are cared for and watched over particularly in houses where only aged people live or their parents are frequently absent by detecting the operating conditions.

[0006] Examples are as follows:

1) Domestic helpers are informed of disorders through telephone lines when the following disorders are detected; a door of toilets is not opened and shut for more than a certain time, a volume of televisors is too high, the operations of various appliances are unnatural such that air conditioners and warm air circulators are simultaneously in operation, or the like.
2) Parents are warned by the screen and voice of televisors when a portable telephone of their children go out of an area supervised by a station in charge of the neighborhood of their house.

[0007] Connections between various appliances for the above-mentioned purposes are conceptionally shown in Figure 1.

[0008] In Figure 1, a refrigerator 1, an air conditioner 2, an electric kotatsu 3, a fluorescent light 4, a microwave oven 5 and a washing machine 6 are connected to a controller (or a CPU) 10 by an electric wire 11, and thus a (sub) network is configured. A televisor 7 and an electric clock 8 are connected to the controller 10 by an infrared ray 12, and thus a (sub) network is configured. A telephone 9 is connected to the controller 10 by a wireless 13, and thus a (sub) network is configured.

[0009] In addition to the above, other means such as supersonic waves or plural means are used for connecting the appliances.

[0010] Also regarding the network, as shown in Figure 1, many appliances and (sub) networks are connected radially from the only controller 10, and additionally as shown in Figure 2 (a), in order to decrease the maximum electric power consumption in factories and buildings, several (sub) networks having a router (which is positioned between plural (sub) networks to realize mutual communication therebetween. In Figure 1, the controller 10 serves for the router. A communication processing function attached to an appliance serves for the router depending on a system and the appliance.) are connected by the router or an appliance serving for the router as a terminal of components thereof. Furthermore, as shown in Figure 2 (b), appliances and (sub) networks are hierarchically connected as trees.

[0011] In Figures 2 (a) and (b), 20 indicates a (sub) network or an appliance as a substantial (sub) network and 30 indicates a router or an appliance serving for the router.

[0012] Full-time custodians as well as information desks and doorbells are occasionally incorporated into a system in factories, office buildings and hospitals.

[0013] Another example is not so complicated but a simple constitution; in the case of connecting a televisor and a video tape recorder, the video tape recorder periodically reads out a time signal in airwaves, which the televisor received, to adjust its built-in clock thereby for the purpose of displaying an exact time.

[0014] Moreover, various kinds of standards and plans therefor (such as ET - 2101 and JEM - 1439) have been decided and proposed in the Electronic Industries Association of Japan, the Japan Electrical Manufacturers' Association and the like in order to effectively perform the functions of the networks.

[0015] Also, communications protocols and the like have been decided or developed.

[0016] For that purpose, equipments and functions such as communication processing functions necessary for performing the appropriate functions of the home networks have been attached to appliances (including sensors) in the stage of manufacturing or studied for attaching.

(Background arts in view of the problems to be solved by the present invention)

[0017] In the above-mentioned configuration of control network systems of appliances, particularly household electric appliances, however, it should be recognized beforehand in the stage of designing the systems that which of the following methods the controller employs for acquiring operation data for controlling the appliances; a method of receiving the operation data transmitted from each of the appliances in changing the operation data such as switching, a method of receiving the operation data by a query from the controller to the appliances, a method of receiving the operation data periodically transmitted from the appliances to the controller, a method of receiving the operation data broadcasted from each of the appliances in changing the operation data, and the like. In terms of the conditions of the household electric appliances, the need to change how the controller acquires the operation data is occasionally caused on each introduction of other household electric appliances.

[0018] For the purpose of linked operations only by household electric appliances, addresses of household electric appliances for receiving operation data should be set at household electric appliances for transmitting the operation data, and additionally addresses of the household electric appliances for transmitting the operation data should be set at the household electric appliances for receiving the operation data. The setting, therefore, should be performed in each of control network systems of household electric appliances.

[0019] On the other hand, the problem is occasionally the electric power consumption of a controller in a system such that the controller receives operation data of household electric appliances to generate a command of operating other household electric appliances in accordance with the received operation data, and thereafter the controller transmits the command to other household electric appliances to control linkedly. That is, the electric power consumption of the household electric appliances is approximately 0.5W on standby, while the electric power consumption of a personal computer as the controller is several tens to 100W. Furthermore, in many cases the controller is constantly operated because of watching data in a network, leading to more electric power consumption thereof.

[0020] Available network wires, means and costs are limited in control network systems of household electric appliances.

[0021] Accordingly, it has been desirable that a technology without the need to change how a controller acquires operation data on each introduction of other household electric appliances is developed subject to many limitations in control network systems of household electric appliances.

[0022] Regarding linked operations between household electric appliances, it has been desirable that a technology of facilitating the setting of addresses and offering less electric power consumption is developed.

[0023] Also, it has been desirable that a technology of linkedly controlling household electric appliances without a controller with a considerable electric power consumption is developed.

DISCLOSURE OF THE INVENTION

[0024] The present invention is intended for solving the above-mentioned problems.

[0025] The following are noted:

Communication definition objects are decided in communications middlewares for connecting applications softwares and sub communications softwares, and thus appliances can be linkedly operated and controlled;

Appliances need specific kinds of other appliances and their operation data for effective operations thereof;

Many appliances already have a function of outputting operating conditions thereof to units at present;

Appliances need kinds and the contents of operation data of other appliances for effective operations thereof;

Specific amounts and kinds of household electric appliances are actually used in houses, and additionally the contents of effective operation and control thereof are simple;

Operators use remote controllers of household electric appliances, while the remote controllers operate specific kinds of the household electric appliances and remote controllers have been common to household electric appliances; and

The contents of operations of household electric appliances related with each other are simple and not

complicated.

[0026] The present aspect of the invention is embodied below.

[0027] An aspect of the invention is characterized in that a network is provided with a controller; the controller acquires operation data (including a measurement by a sensor such as an electric current and a result of processing the measurement) of an appliance (including the sensor and an integral-type appliance of a televisor and a video tape recorder) to be linkedly operated and controlled thereby, and the controller transmits the operation data to another appliance; therefore the appliance maintains in advance information, communications protocols, data or equipments of transmitting conditions such that when and where data such as switching, a change in operation mode and an introduction thereof to the network are transmitted or not, and the appliance transmits necessary operation data to the controller in accordance with the information, communications protocols, data or equipments after adjusting with the controller; the controller, meanwhile, controls the information of transmitting conditions of the appliance, and additionally the controller receives necessary operation data after adjusting with the appliance to transmit the operation data or a direction to another appliance, and furthermore, depending on the situation, the controller provides the appliance with a new setting such that which operation data should be transmitted at what time and a setting such that unnecessary operation data should not be transmitted; and the appliance can accept the setting.

[0028] The above-mentioned configuration enables that the appliances are linkedly operated and the whole network system is effectively operated.

[0029] Another aspect of the invention is characterized in that a network is not provided with a controller; an appliance utilizing operation data of another appliance related therewith has a means of linkedly controlling for operating in accordance with kinds of the related appliance after acquiring the operation data thereof; the appliance exchanges necessary information of transmitting conditions before transmitting and receiving the operation data of the related appliance for the purpose of its appropriate operations; and consequently the appliance acquires the necessary operation data of the related appliance depending on the situation, leading to linked control and operation.

[0030] A further aspect of the invention is characterized by comprising a device for setting linked operations in installing an appliance control network system and introducing another appliance thereto; and in that the device sets the function of linkedly operating at an appliance.

[0031] Three other aspects of the invention are characterized in that an appliance for outputting data according to any one of a second and a third aspects of the invention is a sensor for detecting the presence of persons by voice, motion, infrared ray and the like; and an appliance utilizing the data is an air conditioner. Needless to say, the appliance may be an illuminator, a ventilation fan or the like.

[0032] Three other aspects of the invention are characterized in that an appliance for outputting data is an electric power sensor such as an electric current meter; and an appliance utilizing the data is an air conditioner with a large electric power consumption.

[0033] A still further aspect of the invention is characterized in that a controller watches electric power consumption and electric current consumption of an appliance connected to an appliance control network system; and the controller controls the electric power consumption and the electric current consumption less than a predetermined value. Specifically, before the electric power consumption and the electric current consumption surpass the predetermined value, a load of an appliance with less necessity should be reduced and an appliance should be switched off and also a user should be informed of a predetermined warning.

[0034] A still further aspect of the invention similar to an eighth aspect of the invention is characterized in that a device for setting linked operations, not a controller, controls total electric power consumption of appliances (including NFB and a safety device serving therefor) less than a predetermined value.

[0035] Three other aspects of the invention are characterized in that an appliance and a controller common to appliances are provided with a controller or a means of linkedly controlling in an appliance control network system. Accordingly, the following disorders due to operations by a user can be effectively prevented from being caused; total electric power consumption of appliances surpasses a predetermined value, an air conditioner and a warm air circulator are simultaneously in operation, or the like. In the case of a controller common to appliances, several measures for the disorders can be displayed on a display unit thereof, and thereafter the user can choose from the measures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] Fig. 1 is a view showing a configuration of a home network system of conventional household electric appliances.

[0037] Fig. 2 is a view showing another configuration of a home network system of conventional household electric appliances.

[0038] Fig. 3 is a flow chart showing basic procedures for linked operations between appliances in embodiments of the present invention.

[0039] Fig. 4 is a view showing a constitution of Embodiment 1 of the present invention.

[0040] Fig. 5 is a view showing a configuration of a controller in Embodiment 1 of the present invention.

[0041] Fig. 6 is a view showing another configuration of a controller in Embodiment 1 of the present invention.

[0042] Fig. 7 is a view showing a further configuration of a controller in Embodiment 1 of the present invention.

[0043] Fig. 8 is a view showing information to be transmitted from household electric appliances stored in ROM of the above-mentioned controller and data of other household electric appliances serving for appropriate operations thereof.

[0044] Fig. 9 is a view showing data of household electric appliances necessary for other household electric appliances stored in RAM of the above-mentioned controller and a flow chart showing program procedures for performing functions in accordance with the data.

[0045] Fig. 10 is a view showing a constitution of Embodiment 2 of the present invention.

[0046] Fig. 11 is a flow chart showing procedures for setting and controlling linked operations of an exhaust fan to a cooking stove and an air conditioner in Embodiment 2 of the present invention.

[0047] Fig. 12 is a view showing a principal constitution of Embodiment 3 of the present invention.

[0048] Fig. 13 is a view showing a principal constitution of Embodiment 4 of the present invention.

[0049] Fig. 14 is a view showing a principal constitution of Embodiment 4 of the present invention (in the case of comprising a device for setting linked operations).

[0050] Fig. 15 is a view showing a principal constitution of Embodiment 5 of the present invention.

(Reference characters)

[0051]

1	a refrigerator
2	an air conditioner
3	an electric kotatsu
4	a fluorescent light
5	a microwave oven
6	a washing machine
7	a televisor and a video tape recorder
8	an electric clock
9	a telephone
10	a controller
11	an electric wire
12	an infrared ray
13	a wireless
20	a sub network
30	a router
40	a device for setting linked operations
100	a controller
101	a means of controlling communications
102	a means of controlling information of transmitting condition
103	a means of acquiring operation data
110	a network line
111	a CPU
112	a UI
113	a ROM
114	a RAM
300	a household electric appliance
301	a means of controlling communications
302	a means of maintaining information of transmitting condition
303	a means of controlling transmission of operation data
304	a means of controlling information of transmitting condition
305	a means of controlling operation data
310	a sensor for the presence of persons
311	a means of setting information of transmitting condition
321	a means of transmitting demand data for setting information of transmitting condition
322	a means of setting reception of operation data
323	a means of controlling linked operations
330	a household electric appliance
401	a means of controlling communications
402	a means of transmitting demand data for setting information of transmitting condition
403	a means of transmitting demand data for setting reception of operation data

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0052] The present invention is described below based on preferred embodiments.

(Embodiment 1)

[0053] Embodiment 1 employs a controller for linkedly operating an appliance.

[0054] A configuration of hardwares and softwares in an appliance, which is presuppositional for actually performing Embodiment 1, is described (linked operations in a home network in other Embodiments are basically the same as Embodiment 1.).

[0055] First, it is described by an example whether to execute linked operations in a home network of household electric appliances.

[0056] In order to print with a special font by a printer connected to a computer, the printer decides whether a command of printing with a special font is input from a user in advance of printing. If the command is input, the printer decides whether necessary data for printing with a special font are stored in a predetermined memory. If the data are stored, the printing is executed by reading in the data. If the data are not stored, then a warning is displayed on a display unit to halt the printing. Alternatively, if the command is not input, necessary data for printing with an ordinary font are read out from a memory to execute the printing.

[0057] The execution of linked operations in a home network of household electric appliances is basically the same as the above. That is, when a household electric appliance is provided for a home and started, a prede-

termined access to other household electric appliances is executed through an electric wire in accordance with a user's direction for linked operations and an internal program, and thereafter the household electric appliance decides by a response thereto whether other household electric appliances are linkedly operated, resulting in individual operations or linked operations.

[0058] Next, the contents of a demand for setting information of transmitting conditions, a setting of reception and transmission of operation data and reception of both are described as a part of linked operations by an example.

[0059] Nowadays, many appliances have a function of informing or enabling to inform or direct a user of operating conditions thereof for the purpose of user's convenience of controlling. The examples are as follows; a periodical printout of transmit-receive records in a facsimile, a display of temperature to be set in an air conditioner, and besides household electric appliances a display of mileage, fuel and lubricating oil in a car.

[0060] Moreover, appliances display to a user operating conditions or functions to be performed so that the user chooses which function is performed. For example, many video tape recorders light a recording lamp and display on a display screen of a televisor a standard-speed recording, a 3-speed recording or a commercial-skip recording to be chosen by the user with a remote controller. Air conditioners display on a remote controller a choice between cooling and heating, a setting of temperature, operating time and the like, leading to the performance of user's desirable function.

[0061] In Embodiment 1, household electric appliances basically utilize the functions so that a switching and a choice of operating mode are executed by a user. In the case of linked operations, however, the switching and the choice of operating mode are executed by a controller, not the user. Needless to say, the contents of data and the frequency of exchanges thereof vary with the situation.

[0062] Next, transmission and reception of necessary data for linked operations are described by an example.

[0063] An appliance periodically stores a predetermined operation data or update the data on every change in operating conditions, and additionally the data can be output by a user. This is such that the conditions of units are displayed in a central control room, a driver's seat and the like in plants for vessels and aircrafts; and flight conditions are constantly recorded at a flight recorder in aircrafts.

[0064] The examples are as follows: a display of the number of times documents are corrected in using a word processor; a display of the number of copying papers in a copying machine; a small display of switch-on in a televisor; a display of a channel on which another program than a currently watched program is on record in a video tape recorder; a display of current conditions in an electric rice cooker; and the like.

[0065] Furthermore, a household electric appliance mutually adjusts the performance of its function in conformity with communications protocols. Specifically, facsimiles mutually contact on color printing, paper size and a transmission in a detail mode in conformity with the Protocol CCITT - T30 by Comite consultatif international telegraphique et telehonique, and after a transmitting facsimile generally processes image data for adjusting to both of the transmitting and receiving facsimiles, transmission and reception are executed between the facsimiles. Video tape recorders read out a time signal in airwaves received by a televisor connected thereto to display an exact time to a user and utilize for reserved recording.

[0066] An appliance specifies kinds and the contents of data of other appliances whose data are necessary therefor. For example, operating conditions of air conditioners and refrigerators are generally unnecessary for video tape recorders, particularly, reserved recording. Accordingly, when the household electric appliance demands operating conditions from other household electric appliances or set information of transmitting conditions, a program such that the appliance demands necessary data from only other necessary appliances and only the data are transmitted and received is installed in advance or can be externally set (the program is technologically installed in applications softwares and communications middlewares. Protocols and programs, therefore, have been standardized.).

[0067] Consequently, the above-mentioned functions of household electric appliances are utilized for a home network system of the present invention. In other words, household electric appliances can be incorporated into a home network system by applying the functions.

[0068] Based on the above, although the above-mentioned description is partially repeated, the execution of linked operations of household electric appliances in a home network system of Embodiment 1 and a basic decision on the processing of transmitting and receiving necessary data for the execution are described in accordance with an understandable example referring to a flow chart shown in Figure 3.

[0069] Regarding the execution of linked operations, if household electric appliances are not connected to a home network or do not have other household electric appliances to be linked thereto even in connection with a home network, linked operations are not set and household electric appliances are individually operated. Taking air conditioners for example, if an air conditioner is not connected to a home network or even in connection with a home network the other household electric appliances are appliances such as a facsimile and a video tape recorder which are not related with the operations thereof, the air conditioner is individually operated regardless of the home network. Then, a user of the air conditioner controls switching and power level thereof, or the air conditioner is controlled under a program set by the user in its built-in timer.

[0070] That is, the steps of a1 and a2 in Figure 3 (2)

are executed.

[0071] On the other hand, the steps of b1, b2 and b3 in Figure 3 (1) are executed in the presence of household electric appliances to be linked in a home network. First, a household electric appliance transmits a demand for querying to other household electric appliances in a home network whether to be linked thereto. On a response from any household electric appliances to be linked, the household electric appliance decides that the household electric appliances should be linked and executes the step of b1. That is, the household electric appliance transmits a demand for querying information of transmitting conditions of operation data of the household electric appliances to be linked, and the household electric appliance acquires the information of transmitting conditions in response thereto. Taking the above-mentioned air conditioners for example, when an illuminator is a household electric appliance to be linked in a home network, an air conditioner receives a response from the illuminator and acquires its transmittable operating conditions (lighting conditions and illuminance) and transmitting conditions (periodically or on every change in operating conditions; broadcasting, transmitting to a specific address or transmitting in response to a query).

[0072] Next, when the information of transmitting conditions acquired from the household electric appliances to be linked does not include the transmission of necessary operation data for linked operations to the household electric appliance, or when the transmission of necessary operation data for linked operations is not set, the household electric appliance decides that the information of transmitting conditions of the household electric appliances to be linked should be set and executes the step of b2. That is, the household electric appliance transmits a demand for setting the information of transmitting conditions to the household electric appliances to be linked, and consequently the information of transmitting conditions is set so that operation data of the household electric appliances to be linked are transmitted to the household electric appliance. Subsequently, the step of b3 is executed to complete an initialization of linked operations. That is, the household electric appliance receives operation data transmitted from the household electric appliances to be linked or receives the operation data by a query, and thereafter the household electric appliance sets a storage of the operation data in a memory therefor, resulting in a completion of an initialization of linked operations. Taking illuminators for an example of household electric appliances to be linked to the above-mentioned air conditioners, when an illuminator transmits lighting conditions as operation data not on every change in operating conditions but in response to a query, the household electric appliance transmits to the illuminator a demand for setting information of transmitting conditions such that the illuminator broadcasts or transmits thereto lighting conditions on every change in operating conditions, thereby leading to a setting of information of transmitting conditions. Subsequently, the household electric appliance receives lighting conditions transmitted from the illuminator on every change in operating conditions, and sets a storage thereof in a memory for controlling linkedly to the received lighting conditions, resulting in a completion of an initialization of linked operations.

[0073] In addition, after completing the initialization of linked operations, the steps of a3 and a4, exceptionally a5, in Figure 3 (2) are executed in the case of operating linkedly to a home network. That is, directions of linked operations in Figure 3 are provided by a user of household electric appliances in a home network, depending on a controller and household electric appliances.

[0074] The above-mentioned case is such that air conditioners are operated linkedly to illuminators and door locks; however, linked operations of more household electric appliances are actually executed in a home network. Kinds of identifier codes, therefore, are standardized in advance so that household electric appliances can be incorporated into a home network system. A program is installed in household electric appliances such that sub identifier codes are automatically provided in the presence of plural household electric appliances having the same kinds of identifier codes, leading to a prevention of data interference by transmitting and receiving data provided with the sub identifier codes.

[0075] In condominiums, an interference of a home network system can be caused in neighboring sections (rooms). The measures, therefore, are adopted such that an electric wire is provided with a blocking filter, data are transmitted and received with the provision of different house codes in each section, or the like. Since the measures are publicly known arts, their descriptions are omitted.

[0076] Based on the above, a home network system of Embodiment 1 is described.

[0077] Figure 4 shows a principal configuration of a home network system of Embodiment 1.

[0078] In Figure 4, 100 is a controller, 101 is a means of controlling communications, 102 is a means of controlling information of transmitting conditions and 103 is a means of acquiring operation data.

[0079] 300 is a household electric appliance to be linkedly operated under a controller, 301 is a means of controlling communications, 302 is a means of maintaining information of transmitting conditions, 303 is a means of controlling transmission of operation data, 304 is a means of controlling information of transmitting conditions and 305 is a means of controlling operation data.

[0080] 110 is a network line utilizing an electric wire.

[0081] The means of controlling communications 101 and 301 of the controller and the household electric appliance respectively control exchanges of necessary information with each other and, depending on the situation, other household electric appliances and sensors (both are not shown in Figure 4) by using the network line 110. Specifically, a generation of data to be trans-

mitted, a transmission of telegraphic messages, a reception of telegraphic messages, an extraction of data to be received and the like.

[0082] Figures 5 to 7 specifically show types of configuration of the controller. In Figures 5 to 7, 101 is a network interface unit equivalent to the means of controlling communications 101 shown in Figure 4. 111 is a central process unit (CPU) configured by internal chips. 112 is an input-output (control) unit comprising a user interface (UI). 113 is a ROM programmed by a manufacturer for performing an appropriate function as the controller. 114 is a RAM in which necessary data are properly stored while performing a function as the controller. The CPU, UI, ROM and RAM serve for the means of controlling information of transmitting conditions 102 and the means of acquiring operation data 103 shown in Figure 4. Figure 6 shows a type of the controller which is not provided with the UI and Figure 7 shows a type of the controller which is provided in the CPU with the RAM.

[0083] Each household electric appliance is provided with softwares and hardwares similar to the above, which have different memory capacity and CPU performance.

[0084] Figure 8 shows a part of data stored in the ROM. Figure 8 (1) depicts a table of information to be transmitted from each household electric appliance to a controller. The top row of Figure 8 (1) indicates that a refrigerator should transmit high, average or stop of cooling, on or off of dehumidification and a value of electric power consumption. In the top row, a single asterisk in each item indicates that the refrigerator should transmit on every change in the above-mentioned operating conditions, and double asterisks indicate that the refrigerator should transmit on every change as well as periodically. Figure 8 (2) indicates which household electric appliances are related with effective operations of each household electric appliance. For example, a refrigerator in the top row is operated regardless of other household electric appliances, while an electric power meter in the bottom row is related with household electric appliances having large electric power consumption.

[0085] Each household electric appliance has a function of meeting a demand of a controller. That is, on a demand of a controller for transmitting, the household electric appliance has a function of increasing data item to be transmitted. Another function is to transmit every other minute electric current consumption which is initially transmitted every ten minutes. For the purpose, necessary storage and adjustment can be executed in an internal memory. As a result of a demand of a controller for transmitting, a refrigerator transmits items in the top row of Figure 8 (1) to the controller. The refrigerator may offer more function such as a transmission of inside temperature to be set; however a home network system of Embodiment 1 does not consider more function. A controller, therefore, does not demand more function and is not affected by a transmission of inside temperature to be set or the like.

[0086] Regarding a household electric appliance, the means of maintaining information of transmitting conditions 302 is a memory for maintaining the conditions of transmitting operation data, such as information and routine on when the operation data are transmitted, which operation data are transmitted and to which address the operation data are transmitted. The contents are described as the above-mentioned Figure 8 (1).

[0087] The means of controlling transmission of operation data 303 transmits operation data (controlled thereby) through the means of controlling communications 301 in accordance with the information maintained by the means of maintaining information of transmitting conditions. Specifically, switching, a load of operations, a time signal in airwaves received by a radio, and the like are transmitted periodically or on every change in operating conditions.

[0088] The means of controlling operation data 305 stores operation data of a household electric appliance constantly or periodically.

[0089] The means of controlling information of transmitting conditions 304 informs the means of maintaining information of transmitting conditions 302 of the information of transmitting conditions transmitted from a controller, and updates the information maintained by the means of maintaining information of transmitting conditions depending on the situation. That is, the information should occasionally not be transmitted depending on kinds and the contents of household electric appliances connected to a home network.

[0090] Based on the above, a controller stores in a RAM the contents shown in Figures 8 (1) and (2) with regard to only household electric appliances currently connected to a home network system. Taking the items of an electric power meter shown in Figure 8 (2) for example, the contents shown in Figure 9 (1) are stored. This case is such that code 1 is provided for a refrigerator while codes 1 and 2 are provided for air conditioners, televisors and video tape recorders. Thus, in a home network system the electric power consumption of a household electric appliance is controlled less than a predetermined value by a program, referring to the data of an electric power meter stored in a RAM. Specifically, the refrigerator is kept switched on and one of the air conditioners or the televisors is switched off. The procedures are described in Figure 9 (2).

[0091] Alternatively, a word processor in operation is kept switched on and the refrigerator capable of pausing is switched off, then the controller, the word processor and the televisor are informed that the refrigerator is switched off in consideration of total electric power consumption.

[0092] The means of controlling information of transmitting conditions 102 demands from the means of controlling information of transmitting conditions 304 of a household electric appliance the transmission of information of transmitting conditions such that when and

which information is transmitted, and the information of transmitting conditions is received in response thereto. In addition, the means of controlling information of transmitting conditions demands the transmission of data such that which operating conditions can be transmitted and receives a response thereto. If the response includes the data of operating conditions, the data are transmitted to the means of acquiring operation data by the means of controlling information of transmitting conditions.

[0093] If the response of information of transmitting conditions from a household electric appliance does not include the data of operating conditions, the means of acquiring operation data demands the transmission thereof and receives.

[0094] Based on the above, the operations of household electric appliances are appropriately controlled in a home network system such that a controller is a center thereof.

[0095] Taking a user-friendly facsimile for example, a user is periodically informed by printing that facsimile number of transmitter and receiver, date and time of transmission and reception, the number of papers in transmission and reception, and how many more papers left. Also, a controller is similarly informed.

[0096] The controller, however, is informed not merely by printing but also through an electric wire. Depending on the direction of the controller, it can be informed only that date and time of transmission and reception, the number of papers in transmission and reception, and how many more papers left.

[0097] As a specific means therefor, the controller directs that a flag be provided for only an item to be informed by a home network among transmission items maintained by the means of maintaining information of transmitting conditions 302.

[0098] In a home network system shown in Figure 1, a controller decides which operation data of a household electric appliance can be acquired, and thereafter necessary control is executed. Specifically, a controller causes a facsimile to ring a warning so as to inform a user of papers scarcely left.

[0099] When plural facsimiles are used in an office, each facsimile is provided with an identifier code (ID) by another means as described above and thereby it is decided which facsimile rings a warning.

[0100] In a home network system shown in Figure 2 (a), a control unit of a household electric appliance is properly controlled by a controller. For example, an exhaust fan informed of a lighting of a cooking stove is automatically switched on or leveled up in its power even in operation. For the purpose, a spark plug of a cooking stove detects a switch-on thereof by a user to instantaneously transmit a signal to the controller, which directs the exhaust fan to operate when out of operation or to level up its power to a maximum when in a low power or in an air-conditioned room.

(Embodiment 2)

[0101] In Embodiment 2, a household electric appliance, which utilizes operating conditions of other household electric appliances for controlling operations thereof, acquires the operating conditions from other household electric appliances to be linked.

[0102] Kinds of other household electric appliances whose operation data are necessary for a household electric appliance are specified. For example, indoor temperature and whether an air conditioner is in operation or not are important for a ventilation fan; and particularly the operations of a cooking stove is important for an exhaust fan above the cooking stove, while whether a televisor, a washing machine and an illuminator are in operation or not is not related with the operations thereof. An exhaust fan, therefore, acquires only operation data of necessary household electric appliances such as a cooking stove so as to link the operation data to the operations thereof.

[0103] By contrast, kinds of other household electric appliances, which utilize operation data of an air conditioner, are specified. That is, the operations of an air conditioner are substantially not related with the reception of a facsimile and the operations of hot-water supplies, and additionally simultaneous operation of an air conditioner and either of a warm air circulator and an electric heater means a disorder.

[0104] The equipment of a simple appliance such as a sensor with a timer leads to a raise in costs.

[0105] Accordingly, depending on the kind of another household electric appliance to be installed in a room, the household electric appliance can directly acquire only operation data of necessary household electric appliances not through a controller so as to link the operation data to the effective operations thereof. Embodiment 2 relates to such a case.

[0106] Figure 10 shows a constitution of Embodiment 2.

[0107] In Figure 10, 310 is a household electric appliance which outputs operation data thereof to be utilized for the operations of other household electric appliances. 301 is a means of controlling communications, 302 is a means of maintaining information of transmitting conditions, 303 is a means of controlling transmission of operation data and 311 is a means of setting information of transmitting conditions.

[0108] 320 is a household electric appliance which acquires operation data of other household electric appliances so as to utilize the operation data for linked operations. 301 is a means of controlling communications, 321 is a means of transmitting demand data for setting information of transmitting conditions, 322 is a means of setting reception of operation data and 323 is a means of controlling linked operations.

[0109] The functions of the means of controlling communications 301, the means of maintaining information of transmitting conditions 302 and the means of control-

ting transmission of operation data in the utilized household electric appliance 310 are similar to those of Embodiment 1.

[0110] The means of setting information of transmitting conditions 311 sets in the means of maintaining information of transmitting conditions 302 the information of transmitting conditions transmitted from the utilizing household electric appliance 320 through the network line. For example, a cooking stove informs an exhaust fan thereabove of its operations and which power level of high, medium and low when in operation on every control by a user.

[0111] The means of transmitting demand data for setting information of transmitting conditions 321 in the utilizing household electric appliance demands that the utilized household electric appliance 301 set a predetermined information of transmitting conditions. Specifically, an air conditioner demands that a thermal sensor periodically transmit temperature information; an exhaust fan above a cooking stove demands that the cooking stove transmit the information of its operations and power level in operation, and an air conditioner transmit the information of its operations.

[0112] The means of setting reception of operation data 322 functions similarly to the means of acquiring operation data of Embodiment 1 and acquires operation data transmitted from the utilized household electric appliance periodically or on every change in operating conditions.

[0113] The means of controlling linked operations 323 controls operating conditions of an appliance provided therewith in accordance with the data acquired by the means of setting reception of operation data. Specifically, if a thermal sensor transmits the information of low temperature, an air conditioner reduces its power level.

[0114] An exhaust fan above a cooking stove is not merely automatically switched on when the cooking stove is lit, but also is leveled up in its power to a maximum so that the air heated by the cooking stove is prevented from diffusing into a room when an air conditioner is in operation, and additionally depending on the situation the exhaust fan considers indoor temperature and raises a volume of a televisor in operation.

[0115] Figure 11 shows procedures for performing the functions of an exhaust fan.

[0116] In Figure 11, (1) shows procedures for linked operations to a cooking stove and an air conditioner on an introduction of an exhaust fan to a home network system. (2) shows procedures for linked operations particularly to a cooking stove as a part of a home network system. In Embodiment 2, it is detected by the presence of an air conditioner within a direct reach of ultrasonic signals from an exhaust fan (the presence of its response thereto) whether the air conditioner exists near the exhaust fan.

[0117] In addition, similar functions are performed in linked operations of an audio appliance and an illuminator to a curtain and a window blind. That is, when an audio appliance is switched on at a higher volume than a predetermined volume or an illuminator is switched on, a curtain and a window blind are automatically shut unless a user transmits a direction. Moreover, when an air conditioner is in operation with a great difference between a temperature to be set and indoor temperature, a curtain and a window blind are automatically shut.

[0118] A storage heater for water by utilizing electric power at nighttime can be operated in a full power level after confirming that another appliance consuming great electric power such as a warm air circulator is out of operation at nighttime.

[0119] In Embodiment 2, whether a controller exists or not, a household electric appliance has the means of controlling linked operations, which is an added software, for controlling in accordance with the directions from a network, resulting in appropriate linked operations to another related household electric appliance without causing a raise in costs.

(Embodiment 3)

[0120] Embodiment 3 employs a device for setting linked operations.

[0121] Figure 12 shows a constitution of Embodiment 3.

[0122] In Figure 12, 40 is a device for setting linked operations, which is connected to a home network system on an introduction of a household electric appliance thereto.

[0123] 402 is a means of transmitting demand data for setting information of transmitting conditions, which transmits data for setting information of transmitting conditions to the means of setting information of transmitting conditions 311 of a predetermined household electric appliance through the network line 110.

[0124] 403 is a means of transmitting demand data for setting reception of operation data, which sets a predetermined reception in the means of setting reception of operation data of a household electric appliance.

[0125] 330 is a household electric appliance in which necessary conditions for linked operations are set by the device for setting linked operations. Except that the data to be maintained are set by the device for setting linked operations, the functions of the means of maintaining information of transmitting conditions 302, the means of controlling transmission of operation data 303, the means of setting information of transmitting conditions 311, the means of setting reception of operation data 322 and the means of controlling linked operations 323 are similar to those of Embodiments 1 and 2.

[0126] In Embodiment 3, a device comprising an integrated circuit into which a means of communicating, a means of displaying, a means of inputting and various commands are incorporated is necessary in setting initial linked operations and introducing a household electric appliance to a home network system, while the device is unnecessary thereafter and predetermined

household electric appliances are linkedly operated without a controller.

[0127] Specifically, a personal computer reads in a program in setting a home network; a necessary circuit for a home network is incorporated in advance into household electric appliances connected thereto; the program accesses all of the household electric appliances by a signal of a wireless or an electric wire for every setting object in the home network such as air conditioning and energy saving; and the program displays the household electric appliances and the items of linked operations depending on the situation, leading to proper setting of linked operations and necessary displays. Furthermore, predetermined household electric appliances are linkedly operated without a controller, resulting in less electric power consumption. (A software and a hardware in consideration of a home network system are incorporated into household electric appliances in the stage of manufacturing.)

(Embodiment 4)

[0128] Embodiment 4 applies Embodiments 2 and 3 to an air conditioner to be linkedly operated after receiving the data from a sensor for the presence of persons. Figure 13 shows an application of Embodiment 2 and Figure 14 shows an application of Embodiment 3.

[0129] In Embodiment 4, a sensor for the presence of persons is installed in a room provided with an air conditioner so as to detect the presence of persons by infrared ray from the persons and a movement of the source of infrared ray.

[0130] A sensor for the presence of persons detects the absence of persons to inform an air conditioner of the absence. Thereafter, the air conditioner informed thereof is leveled down in its power, and is switched off and on standby after the absence for a predetermined time such as an hour. In the case of few persons in offices, the air conditioner may be leveled down in its power or an angle of a damper thereof may be decreased.

[0131] Alternatively, an electric current meter is applied in substitution for a sensor for the presence of persons so that the electric power consumption of an air conditioner is maintained at a predetermined value or less and the electric power consumption in the whole house or office is maintained at a predetermined value or less. Thus, the electric power consumption of another appliance such as a personal computer can be increased in a house or a building. A fan around an air conditioner can start to be operated in accordance with a decrease in the power level of the air conditioner. In an office, an air conditioner can be leveled up in its power so as to cool the office during nonuse of a word processor, a personal computer and the like at lunchtime and before work in the morning as well as when indoor temperature is preferably lowered due to the walking of an office worker. After starting work the air conditioner can be leveled down in its power so that the indoor temperature gradually changes to a temperature appropriate for desk work and thereafter somewhat high temperature with a decrease in electric power consumption, and consequently the office worker can maintain motivations (the office worker loses motivations and becomes sleepy due to the maintenance of a certain temperature, resulting in a decrease in the efficiency of working for the whole office).

(Embodiment 5)

[0132] Embodiment 5 incorporates an integrated control device for a home network system into a remote controller (a remote control device for a user) common to an air conditioner, a televisor, a video tape recorder and the like. Figure 15 shows a constitution of Embodiment 5.

[0133] A remote controller common to an air conditioner, a televisor, a video tape recorder and an audio appliance has been usable or frequently considered to be usable in recent years.

[0134] In this case, the remote controller not merely comprises a transmitter of infrared ray or electromagnetic wave for controlling the operations of various appliances but also instantaneously causes the control of a user to be reflected in a transmission of a direction to an appliance to be controlled. Accordingly, in the case of an air conditioner, a televisor and a video tape recorder, it is particularly made more effective that various appliances in a home network system are operated with the reflection of the control of the user, for example, an adjustment of electric power consumption, an open and shut of a curtain and a window blind, and a switch-on of an illuminator linked with a clock.

[0135] In addition, when total electric power consumption of household electric appliances surpasses a limited value due to a switch-on and a power level-up of a household electric appliance by the user, the remote controller displays thereabout so as to cause the user to choose which another household electric appliance is switched off. Thus, an inconvenience due to a sudden blowout of a fuse and a switch-off of NFB can be prevented such that not merely all appliances including an illuminator are suddenly switched off at nighttime but also all data being currently stored in a word processor are deleted.

[0136] The remote controller can easily warn the user of an unnatural direction such that an air conditioner is switched on during the operation of a warm air circulator.

[0137] The present invention was described above based on the embodiments and is not limited thereto. That is, the following changes and modifications may be made thereto.

1) An appliance connected to a home network system does not have elements (constitutions, requirements and specified matters) of the present invention.

2) The manners of claims are concurrently employed. That is, an appliance is controlled by a controller, while another appliance is not controlled.
3) In Embodiment 3, an initial setting is executed also using an exclusive connection line.
4) A utilized appliance is not a household electric appliance but a sensor for the presence of persons, electric power consumption and illuminance. Thus, a utilizing appliance such as an air conditioner and an illuminator is leveled down in its power or switched off in the absence of persons. Alternatively, a utilized appliance is a switch. Thus, a heater using kerosene for fuel is switched on so that indoor temperature rises and the density of carbon dioxide increases, and thereafter a ventilation fan is switched on.
5) In Embodiment 3, the functions of a personal computer can be used for a means of communicating, a means of displaying and a means of inputting. Consequently, linked operations are substantially set in a disk storing a necessary program. The setting can be executed not merely by plugging in an electric source input unit besides a transmission unit of a wearable device for setting linked operations but also by employing various means such as an input device by a user.
6) Regarding a decrease in total electric power consumption, when a user directs another appliance to be switched on, a remote controller has a function of displaying that the user should choose which appliance is switched off due to the excess in total electric power consumption. The procedures are as follows; an allowance for electric power supply is calculated in advance by total electric power consumption of appliances in operation and a capacity for electric power supply (referring to Figure 9 (2)), and a warning is displayed if electric power consumption of another appliance which is switched on by the user is not within the allowance (similar to the steps of a1, a3 and a5 in Figure 3 (2)).
7) An appliance is not limited to a household electric appliance and a home network system is intended not merely for a house but also for a section of an office.
8) When an installation of another appliance in a home network system leads to the presence of plural controllers and means of controlling linked operations therein, a program is incorporated therein such that second controller or second means of controlling linked operations is not operated.

INDUSTRIAL APPLICABILITY

[0138] It is to be understood from the above description that linked operations of appliances are easily and flexibly set according to the present invention.

[0139] An embodiment offers less electric power consumption.

[0140] An inconvenience due to a user's careless control can be prevented.

Claims

1. A control network system of an appliance comprising a controller and a plurality of appliances connected through a network;

   wherein the appliances acquire necessary operation data of another appliance from the controller and utilize the operation data for controlling an efficient operation thereof;
   each of said appliances comprising:

      a means of maintaining an information of a transmitting condition of operation data thereof;
      a means of controlling the operation data thereof by a predetermined program;
      a means of controlling the information of the transmitting condition for receiving a demand for transmitting the information of the transmitting condition by said controller, and transmitting and setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in response thereto; and
      a means of controlling a transmission of the operation data for transmitting the operation data thereof controlled by said means of controlling the operation data in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition;

   said controller comprising:

      a means of controlling the information of the transmitting condition for demanding a transmission of the data maintained by said means of maintaining the information of the transmitting condition from said means of controlling the information of the transmitting condition of each of said appliances, receiving the information of the transmitting condition transmitted from each of the appliances in response thereto, setting a control item in the information of the transmitting condition, and demanding a setting of the information of the transmitting condition of a control item when the information of the transmitting condition does not include the necessary control item; and

a means of acquiring the operation data for acquiring the operation data when the information of the transmitting condition of each of said appliances received by said means of controlling the information of the transmitting condition includes a transmission of the operation data of the appliance to said controller, and demanding a transmission of the operation data from an appliance to acquire the operation data when the information of the transmitting condition of each of said appliances received by said means of controlling the information of the transmitting condition does not include the transmission of the operation data of the appliance to said controller.

2. A control network system of an appliance comprising a plurality of appliances connected through a network;

wherein each of the appliances receives necessary operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;
each of the appliances whose operation data are utilized comprising:

a means of maintaining an information of a transmitting condition of operation data thereof;
a means of controlling a transmission of the operation data for controlling the operation data thereof by a predetermined program, and transmitting the operation data thereof in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition; and
a means of setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;

each of the appliances utilizing operation data of another appliance comprising:

a means of transmitting predetermined data for setting the information of the transmitting condition to the means of setting the information of the transmitting condition of another related appliance;
a means of setting a reception of the operation data for receiving the operation data transmitted from another appliance in accordance with the demand data for setting the information of the transmitting condition, and setting a necessary storage of the operation data in a corresponding memory thereto; and
a means of controlling a linked operation for controlling an efficient operation thereof in accordance with the operation data of another appliance received and set by the means of setting the reception of the operation data.

3. A control network system of an appliance comprising a plurality of appliances which are connected through a network and are set so as to be linkedly operated by a wearable device for setting a linked operation;

wherein each of the appliances receives operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;
each of said appliances comprising:

a means of maintaining an information of a transmitting condition of operation data thereof;
a means of controlling a transmission of the operation data for controlling the operation data thereof by a predetermined program, and transmitting the operation data thereof in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition;
a means of setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;
a means of setting a reception of the operation data for receiving the operation data transmitted from another appliance in accordance with the demand data for setting the information of the receiving condition received through the network, and setting a necessary storage of the operation data in a corresponding memory thereto; and
a means of controlling a linked operation for controlling an efficient operation thereof in accordance with the operation data of another appliance received and set by the means of setting the reception of the operation data;

said wearable device for setting a linked operation comprising:

a means of transmitting demand data for setting the information of the transmitting condition for transmitting predetermined demand data for setting the information of the transmitting condition to each of the appliances, and setting the information of the transmitting condition in setting the network and introducing another appliance thereto; and

a means of transmitting demand data for setting the information of the receiving condition of the operation data for transmitting the demand data for setting the reception of the operation data to each of the appliances, and receiving and setting the operation data in setting the network and introducing another appliance thereto.

4. A control network system of an appliance comprising a plurality of appliances including an air conditioner and a sensor for a presence of a person, which are connected through a network;

wherein each of the appliances receives necessary operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;

said sensor for a presence of a person comprising:

a means of maintaining an information of a transmitting condition of detection data for a presence of a person which are operation data thereof;

a means of controlling a transmission of the operation for controlling the detection data for the presence of the person by a predetermined program, and transmitting the controlled detection data for the presence of the person in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition; and

a means of setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;

said air conditioner comprising:

a means of transmitting predetermined demand data for setting the information of the transmitting condition to the means of setting the information of the transmitting condition of said sensor for the presence of the person;

a means of setting the reception of the operation data for receiving the detection data for the presence of the person transmitted from the sensor for the presence of the person in accordance with the demand data for setting the information of the transmitting condition, and setting a necessary storage of the detection data for the presence of the person in a corresponding memory thereto; and

a means of controlling a linked operation for controlling an operation of the air conditioner in accordance with the detection data for the presence of the person received and set by the means of setting the reception of the operation data.

5. A control network system of an appliance comprising a plurality of appliances including an air conditioner and an electric power sensor, which are connected through a network;

wherein each of the appliances receives necessary operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;

said electric power sensor comprising:

a means of maintaining an information of a transmitting condition of detection data for an electric power which are operation data thereof;

a means of controlling a transmission of the operation for controlling the detection data for the electric power by a predetermined program, and transmitting the controlled detection data for the electric power in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition; and

a means of setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;

said air conditioner comprising:

a means of transmitting predetermined de-

mand data for setting the information of the transmitting condition to the means of setting the information of the transmitting condition of said electric power sensor;
a means of setting a reception of the operation data for receiving the detection data for the electric power transmitted from the electric power sensor in accordance with the demand data for setting the information of the transmitting condition, and setting a necessary storage of the detection data for the electric power in a corresponding memory thereto; and
a means of controlling a linked operation for controlling an operation of the air conditioner in accordance with the detection data for the electric power of the electric power sensor received and set by the means of setting the reception of the operation data.

6. A control network system of an appliance comprising a plurality of household electric appliances including an air conditioner and a sensor for a presence of a person, which are connected through a network and are set so as to be linkedly operated by a wearable device for setting a linked operation;

wherein each of the appliances receives necessary operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;
said sensor for a presence of a person comprising:

a means of maintaining an information of a transmitting condition of detection data for a presence of a person which are operation data thereof;
a means of controlling a transmission of the operation for controlling the detection data for the presence of the person by a predetermined program, and transmitting the controlled operation data thereof in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition; and
a means of setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;

said air conditioner comprising:

a means of setting a reception of the operation data for receiving the detection data for the presence of the person transmitted from the sensor for the presence of the person in accordance with the demand data for setting a method of the receiving condition received through the network, and setting a necessary storage of the detection data for the presence of the person in a corresponding memory thereto; and
a means of controlling a linked operation for controlling an operation of the air conditioner in accordance with the detection data for the presence of the person received and set by the means of setting the reception of the operation data;

said wearable device for setting a linked operation comprising:

a means of transmitting demand data for setting the information of the transmitting condition for transmitting demand data for setting the information of the transmitting condition to the appliances including said sensor for the presence of the person, and setting the information of the transmitting condition in setting the network and introducing another appliance thereto; and
a means of transmitting demand data for setting the reception of the operation data for transmitting the information of the receiving condition of the operation data to the appliances including said air conditioner, and receiving and setting the operation data in setting the network and introducing another appliance thereto.

7. A control network system of an appliance comprising a plurality of household electric appliances including an air conditioner and an electric power sensor, which are connected through a network and are set so as to be linkedly operated by a wearable device for setting a linked operation;

wherein each of the appliances receives necessary operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;
said electric power sensor comprising:

a means of maintaining an information of a transmitting condition of detection data for an electric power which are operation data thereof;
a means of controlling a transmission of the operation for controlling the detection data

for the electric power by a predetermined program, and transmitting the controlled operation data thereof in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition; and

a means of setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;

said air conditioner comprising:

a means of setting a reception of the operation data for receiving the detection data for the electric power transmitted from the electric power sensor in accordance with the demand data for setting a method of the receiving condition received through the network, and setting a necessary storage of the detection data for the electric power in a corresponding memory thereto; and

a means of controlling a linked operation for controlling an operation of the air conditioner in accordance with the detection data for the electric power received and set by the means of setting the reception of the operation data;

said wearable device for setting a linked operation comprising:

a means of transmitting demand data for setting the information of the transmitting condition for transmitting demand data for setting the information of the transmitting condition to the appliances including said electric power sensor, and setting the information of the transmitting condition in setting the network and introducing another appliance thereto; and

a means of transmitting demand data for setting the reception of the operation data for transmitting the information of the receiving condition of the operation data to the appliances including said air conditioner, and receiving and setting the operation data in setting the network and introducing another appliance thereto.

8. A control network system of an appliance comprising a controller and a plurality of appliances connected through a network;

wherein the appliances acquire necessary operation data of another appliance from the controller and utilize the operation data for controlling an efficient operation thereof;

each of said appliances comprising:

a means of maintaining an information of a transmitting condition of operation data including at least one of an electric power consumption and an electric current consumption thereof;

a means of controlling the operation data including at least one of the electric power consumption and the electric current consumption thereof by a predetermined program;

a means of controlling the information of the transmitting condition for receiving a demand for transmitting the information of the transmitting condition including at least one of the electric power consumption and the electric current consumption by said controller, and transmitting and setting the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition in response thereto;

a means of controlling a transmission of the operation data for transmitting the operation data including at least one of the electric power consumption and the electric current consumption thereof controlled by said means of controlling the operation data in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition; and

a means of controlling the electric power consumption for controlling at least one of the electric power consumption and the electric current consumption in accordance with a control by said controller;

said controller comprising:

a means of controlling the information of the transmitting condition for demanding a transmission of the data maintained by said means of maintaining the information of the transmitting condition from said means of controlling the information of the transmitting condition of each of said appliances, receiving the information of the transmitting condition transmitted from each of the appliances in response thereto, setting a control item in the information of the transmitting condition, and demanding a setting of the information of the transmit-

ting condition of a control item when the information of the transmitting condition does not include the necessary control item including at least one of the electric power consumption and the electric current consumption;

a means of acquiring the operation data for acquiring the operation data when the information of the transmitting condition of each of said appliances received by said means of controlling the information of the transmitting condition includes the operation data including at least one of the electric power consumption and the electric current consumption of the appliance, and demanding a transmission of the operation data from an appliance to acquire the operation data when the information of the transmitting condition of each of said appliances received by said means of controlling the information of the transmitting condition does not include the operation data including at least one of the electric power consumption and the electric current consumption of the appliance; and

a means of controlling a total electric power consumption for controlling so that at least one of a total electric power consumption and a total electric current consumption of the plurality of appliances connected through the network does not surpass a predetermined value in accordance with the operation data acquired by said means of acquiring the operation data.

9. A control network system of an appliance comprising a plurality of appliances which are connected through a network and are set so as to be linkedly operated by a wearable device for setting a linked operation;

wherein each of the appliances receives operation data of another appliance through the network and controls an efficient operation thereof to be linked to the received operation data;

each of said appliances comprising:

a means of maintaining an information of a transmitting condition of operation data including at least one of an electric power consumption and an electric current consumption thereof;

a means of controlling a transmission of the operation data for controlling the operation data including at least one of the electric power consumption and the electric current consumption thereof by a predetermined program, and transmitting the operation data thereof in accordance with the information of the transmitting condition maintained by said means of maintaining the information of the transmitting condition;

a means of setting the information of the transmitting condition including at least one of the electric power consumption and the electric current consumption maintained by said means of maintaining the information of the transmitting condition in accordance with predetermined demand data for setting the information of the transmitting condition received through the network;

a means of setting a reception of the operation data for receiving the operation data including at least one of the electric power consumption and the electric current consumption transmitted from another appliance in accordance with the demand data for setting the information of the receiving condition received through the network, and setting a necessary storage of the operation data in a corresponding memory thereto; and

a means of controlling a linked operation for controlling an efficient operation thereof in accordance with the operation data of another appliance received and set by the means of setting the reception of the operation data;

said wearable device for setting a linked operation comprising:

a means of transmitting demand data for setting the information of the transmitting condition for transmitting predetermined demand data for setting the information of the transmitting condition including at least one of the electric power consumption and the electric current consumption to each of the appliances, and setting the information of the transmitting condition in setting the network and introducing another appliance thereto; and

a means of transmitting demand data for setting the information of the receiving condition of the operation data for transmitting demand data for setting the reception of the operation data including at least one of the electric power consumption and the electric current consumption to each of the appliances, and receiving and setting the operation data in setting the network and introducing another appliance thereto.

10. A control network system of an appliance according to any one of Claims 1 to 9,

wherein an operation of at least one of said plurality of appliances connected through the network can be directly controlled by a user with a common remote controller; and
said controller or said means of controlling a linked operation is provided for said remote controller.

11. A control network system of an appliance according to Claim 10, wherein said remote controller comprises a means of displaying a warning of a disorder when the disorder is caused such that at least one of a total electric power consumption and a total electric current of the plurality of appliances surpasses a limited value due to an operation of another appliance by the user.

12. A control network system of an appliance according to any one of Claims 1 to 9, wherein a remote controller of at least one of said plurality of appliances connected through the network comprises a means of displaying a warning of a disorder when the disorder is caused such that at least one of a total electric power consumption and a electric current of the plurality of appliances surpasses a limited value due to an operation of another appliance by a user.

Fig. 1

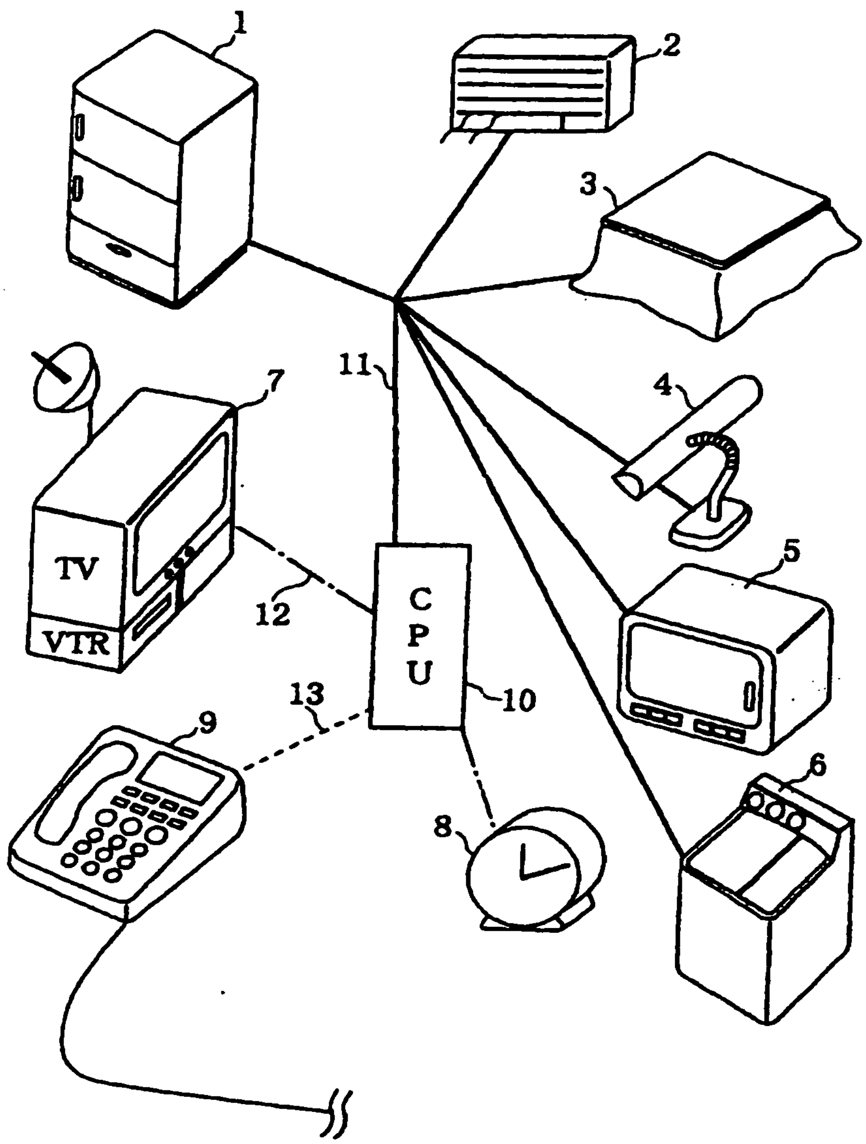


Fig. 2

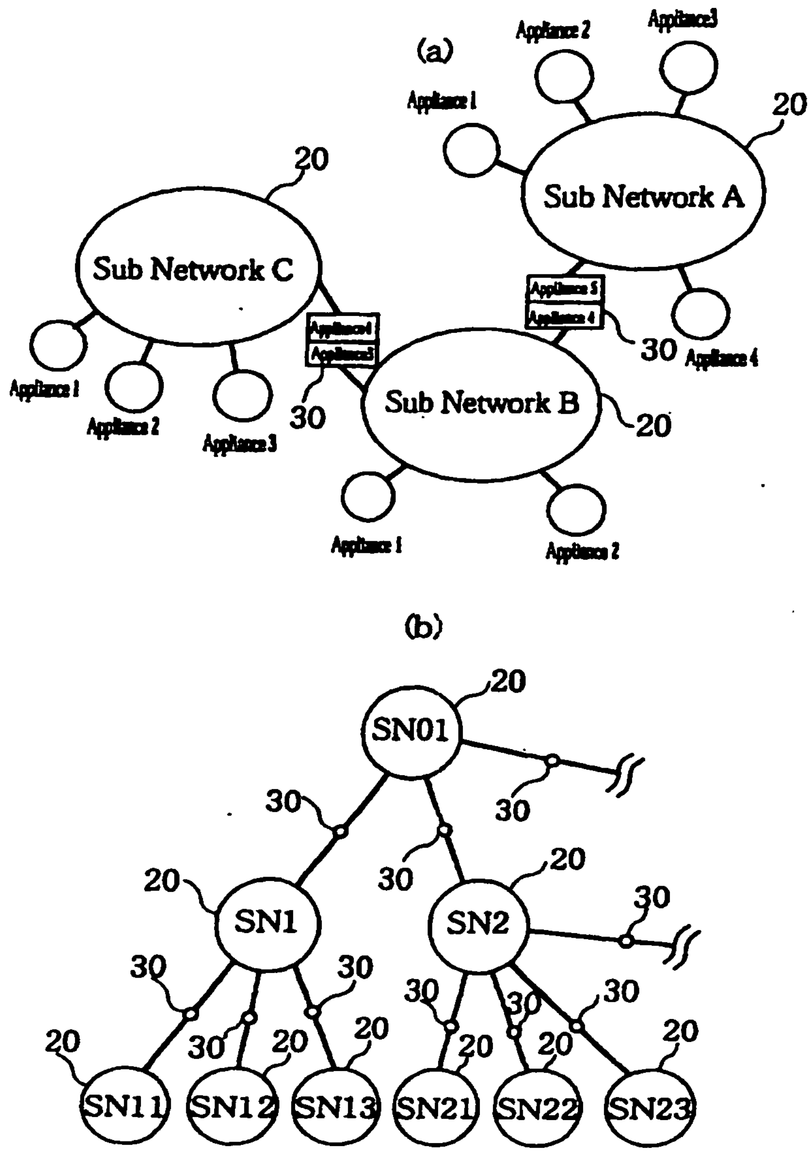

(a)
Appliance 2
Appliance3
Appliance 1
20
Sub Network A
20
Sub Network C
Appliance 5
Appliance 4
Appliance4
Appliance5
30
Appliance 4
Appliance 1
Appliance 2
Appliance 3
30
Sub Network B
20
Appliance 1
Appliance 2
(b)
20
SN01
30
30
30
20
20
SN1
SN2
30
30
30
30
30
30
20
30
20
20
20
20
20
SN11
SN12
SN13
SN21
SN22
SN23

Fig. 3

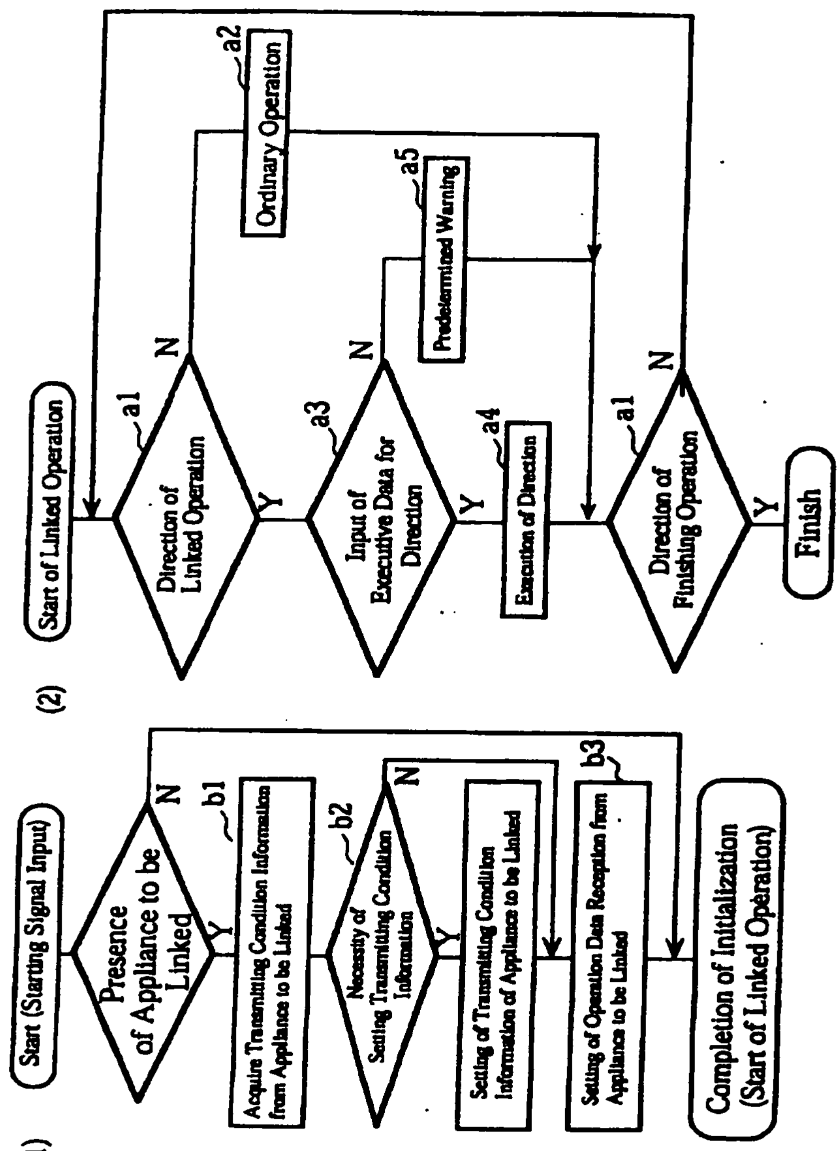

(1)
Start (Starting Signal Input)
Presence of Appliance to be Linked
Y
N
b1
Acquire Transmitting Condition Information from Appliance to be Linked
b2
Necessity of Setting Transmitting Condition Information
Y
N
Setting of Transmitting Condition Information of Appliance to be Linked
b3
Setting of Operation Data Reception from Appliance to be Linked
Completion of Initialization (Start of Linked Operation)
(2)
Start of Linked Operation
a1
Direction of Linked Operation
Y
N
a2
Ordinary Operation
a3
Input of Executive Data for Direction
Y
N
a5
Predetermined Warning
a4
Execution of Direction
a1
Direction of Finishing Operation
Y
N
Finish

Fig. 4

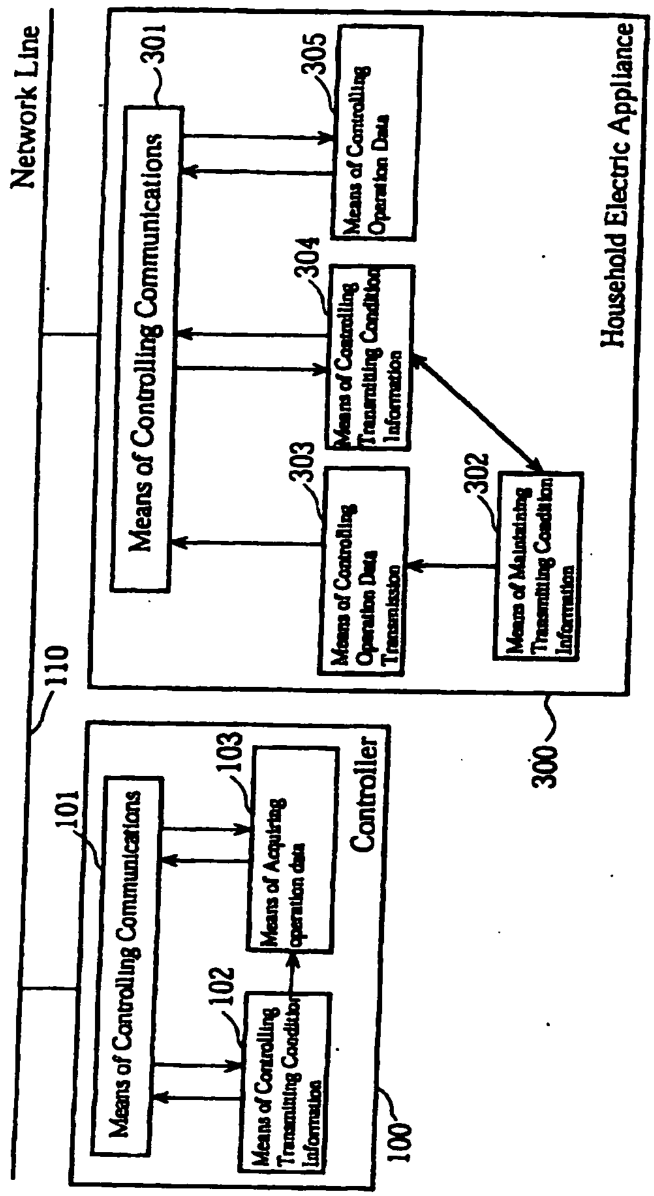

Network Line
110
Household Electric Appliance
300
Means of Controlling Communications
301
Means of Controlling Operation Data
305
Means of Controlling Transmitting Condition Information
304
Means of Controlling Operation Data Transmission
303
Means of Maintaining Transmitting Condition Information
302
Controller
100
Means of Controlling Communications
101
Means of Controlling Transmitting Condition Information
102
Means of Acquiring operation data
103

Fig. 5

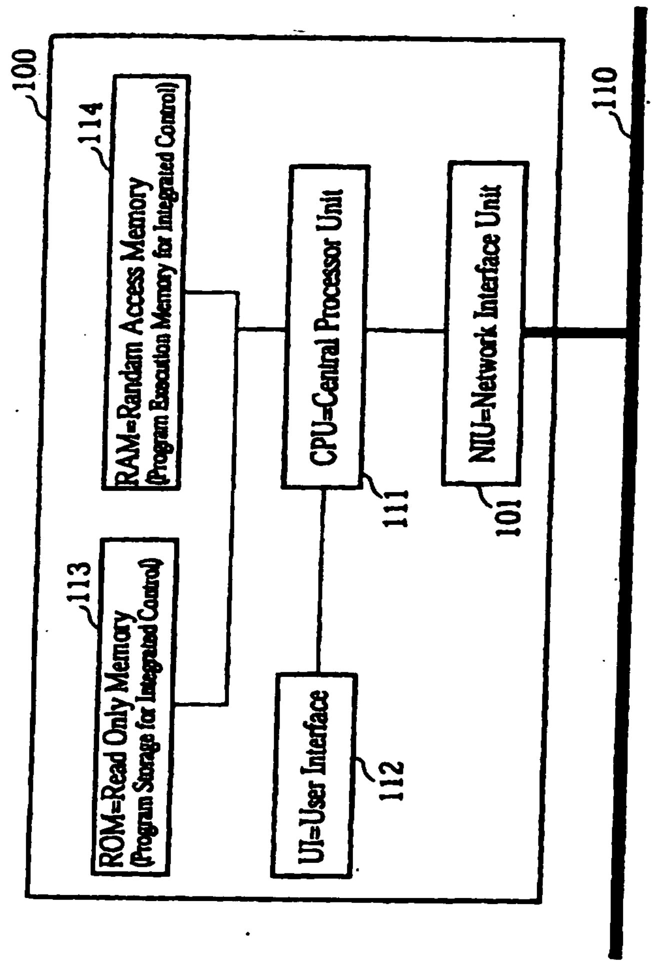

100
RAM=Randam Access Memory
(Program Execution Memory for Integrated Control)
114
ROM=Read Only Memory
(Program Storage for Integrated Control)
113
CPU=Central Processor Unit
111
UI=User Interface
112
NIU=Network Interface Unit
101
110

Fig. 6

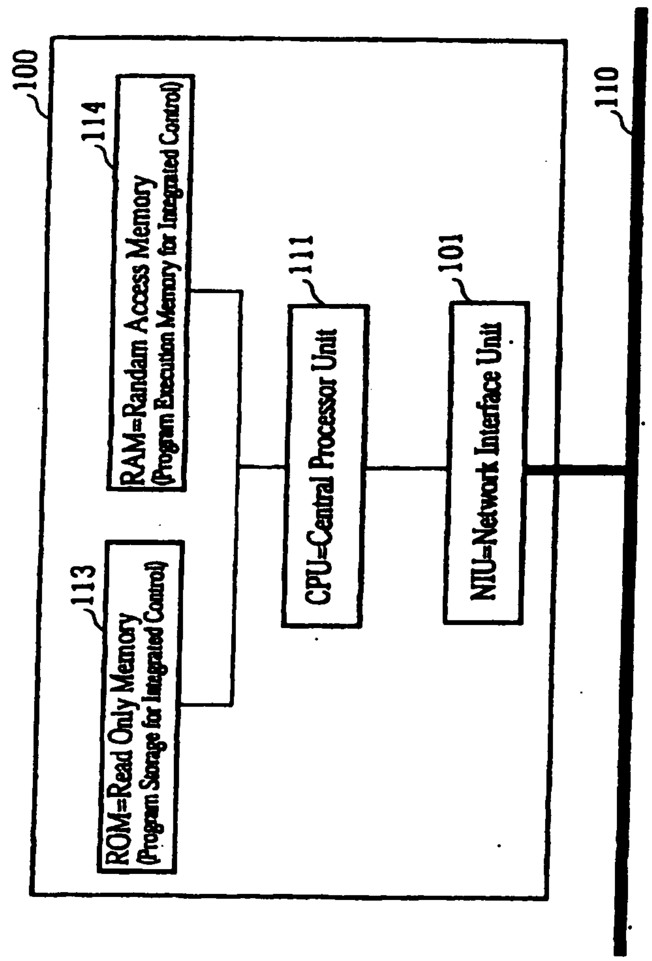

100
114
RAM=Randam Access Memory
(Program Execution Memory for Integrated Control)
113
ROM=Read Only Memory
(Program Storage for Integrated Control)
111
CPU=Central Processor Unit
101
NIU=Network Interface Unit
110

Fig. 7

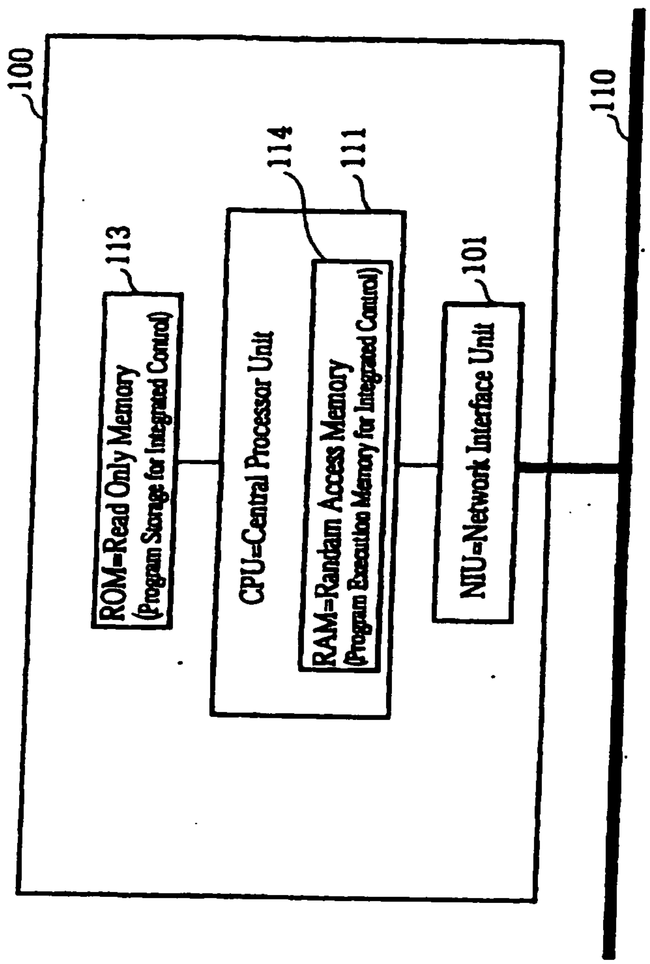

100
110
113
ROM=Read Only Memory
(Program Storage for Integrated Control)
114
111
CPU=Central Processor Unit
RAM=Randam Access Memory
(Program Execution Memory for Integrated Control)
101
NIU=Network Interface Unit

Fig. 8

(1)

Refrigerator	※Cooling	※Dehumidification	※ Electric Power ※ Consumption	Transmission Address
	High,Average or Stop	On or Off	KW	---
Air Conditioner	※ Cooling	※Dehumidification	※ ※ Heating	Transmission Address
	High,Average or Stop	On or Off	High,Average or Stop	---
⋮	⋮			
Ventilation Fan	※Operation	※ Electric Power Consumption	---	
	High,Average,low or Stop	KW	---	

(2)

Refrigerator	
Air Conditioner	Thermal sensor,Illuminator, Lock of Door ---
Ventilation Fan	Cooking Stove,Microwave Oven,Thermal sensor,Gas Sensor ---
⋮	⋮
Electric Power Meter	Refrigerator,Air Conditioner,Electric Kotatsu,Televisor ---

Fig. 9

(1)

Electric Power Meter	Refrigerator	Air Conditioner	Televisor	Video Tape Recorder	---
	REF1	AC1	TV1	VTR1	---
		AC2	TV2	VTR2	

(2)

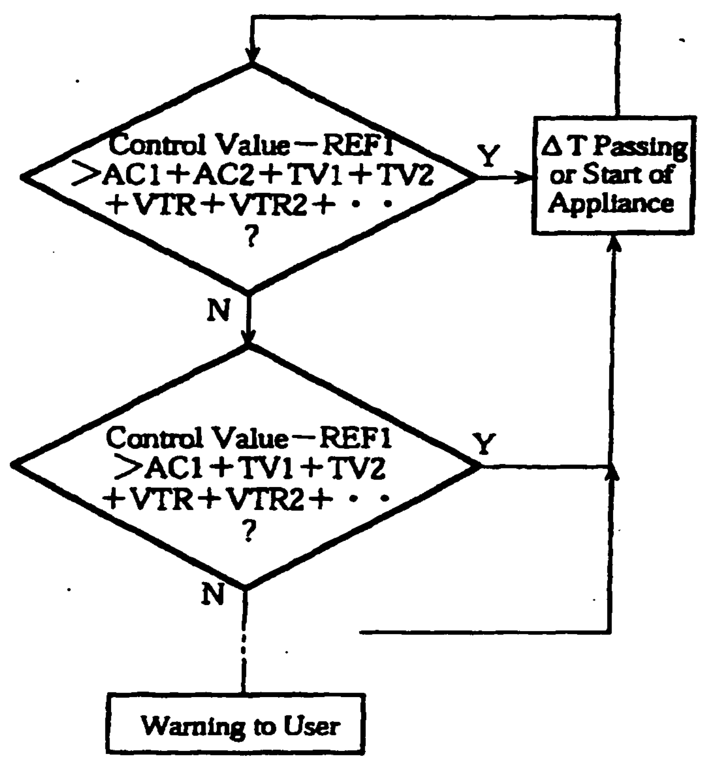


Fig.10

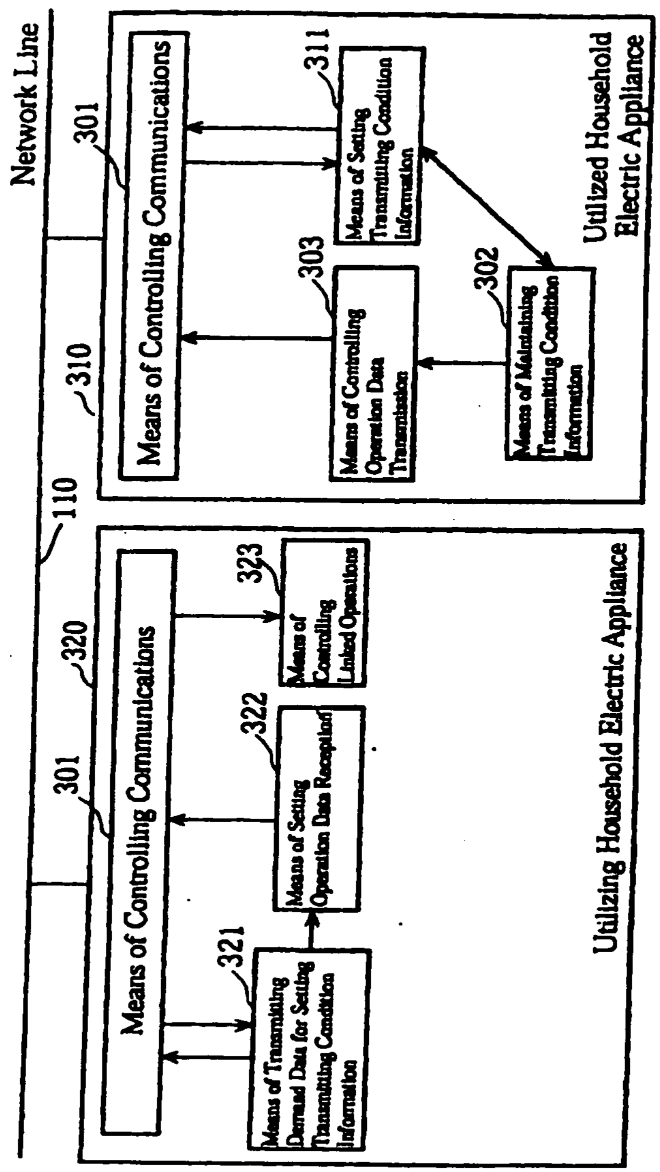

Network Line
110
310
301
Means of Controlling Communications
311
Means of Setting Transmitting Condition Information
303
Means of Controlling Operation Data Transmission
302
Means of Maintaining Transmitting Condition Information
Utilized Household Electric Appliance
320
301
Means of Controlling Communications
321
Means of Transmitting Demand Data for Setting Transmitting Condition Information
322
Means of Setting Operation Data Reception
323
Means of Controlling Linked Operations
Utilizing Household Electric Appliance

Fig. 11

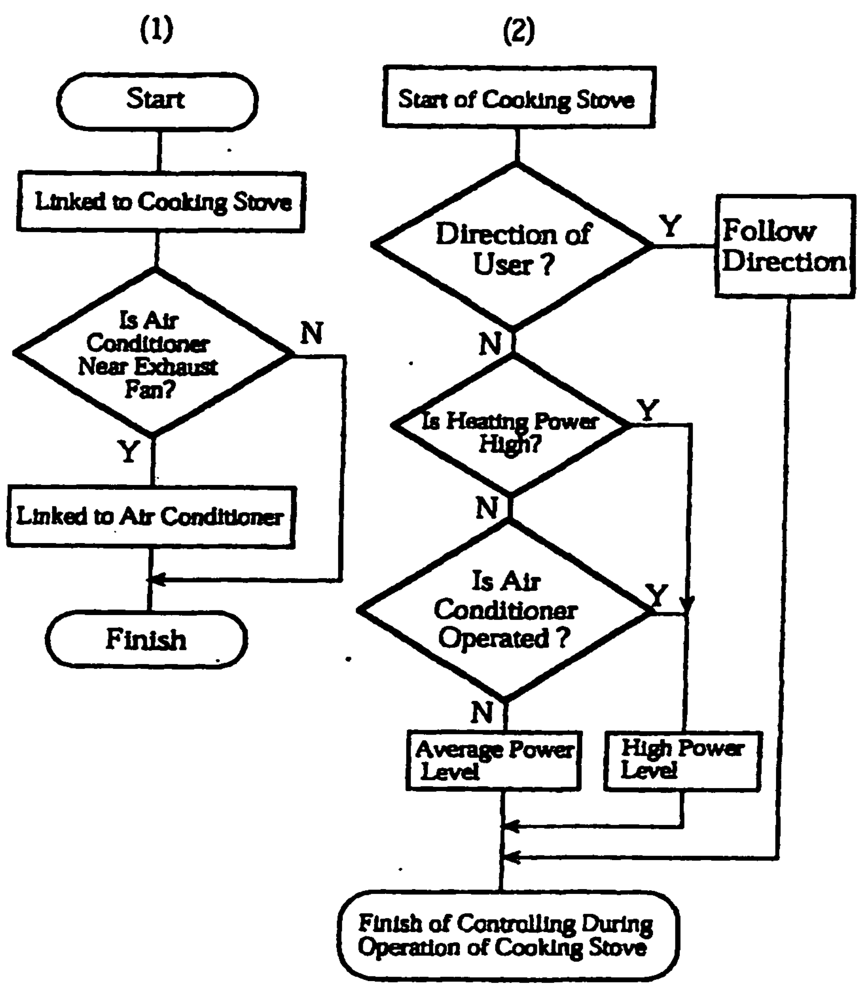

(1)
Start
Linked to Cooking Stove
Is Air Conditioner Near Exhaust Fan?
N
Y
Linked to Air Conditioner
Finish
(2)
Start of Cooking Stove
Direction of User ?
Y
Follow Direction
N
Is Heating Power High?
Y
N
Is Air Conditioner Operated ?
Y
N
Average Power Level
High Power Level
Finish of Controlling During Operation of Cooking Stove

Fig. 12

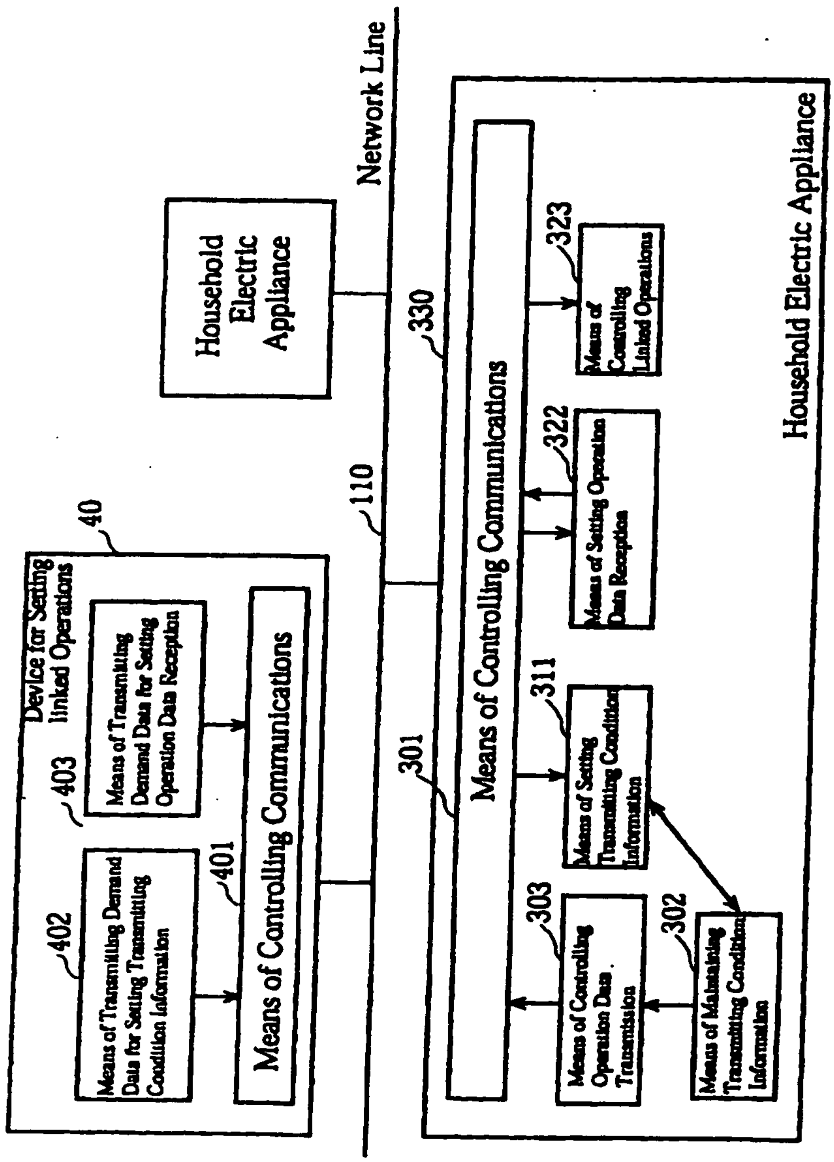

Network Line
110
Household Electric Appliance
40
Device for Setting linked Operations
403
Means of Transmitting Demand Data for Setting Operation Data Reception
402
Means of Transmitting Demand Data for Setting Transmitting Condition Information
401
Means of Controlling Communications
330
Household Electric Appliance
301
Means of Controlling Communications
323
Means of Controlling Linked Operations
322
Means of Setting Operation Data Reception
311
Means of Setting Transmitting Condition Information
303
Means of Controlling Operation Data Transmission
302
Means of Maintaining Transmitting Condition Information

Fig. 13

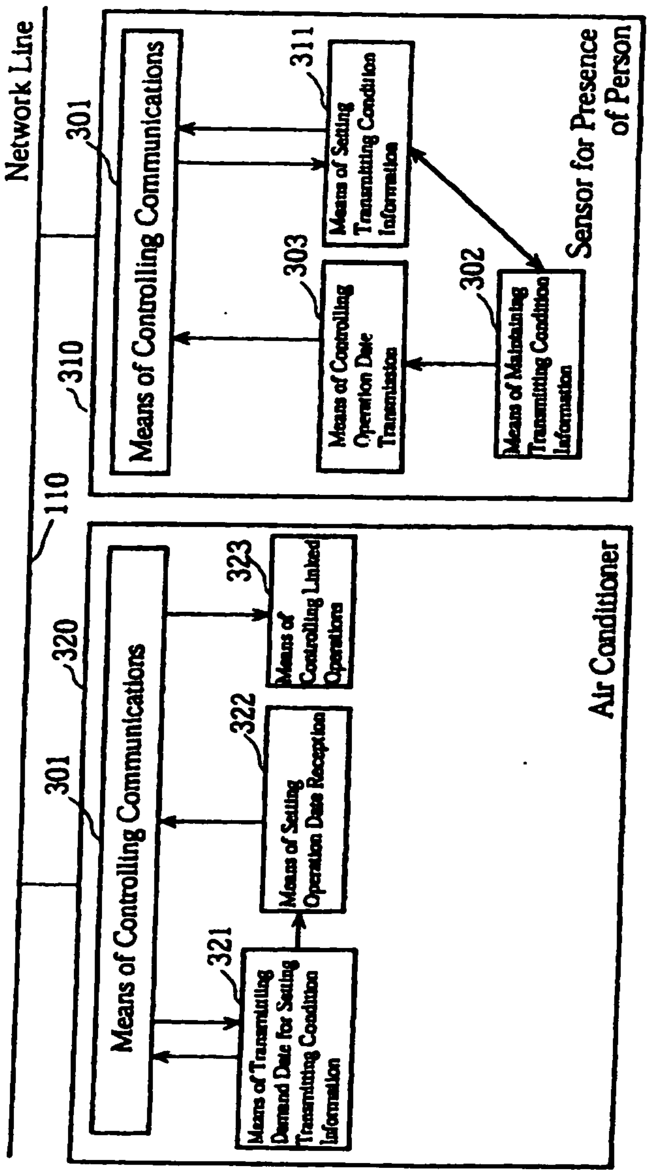

Network Line
110
301
310
Means of Controlling Communications
311
Means of Setting Transmitting Condition Information
303
Means of Controlling Operation Date Transmission
302
Means of Maintaining Transmitting Condition Information
Sensor for Presence of Person
301
320
Means of Controlling Communications
323
Means of Controlling Linked Operations
322
Means of Setting Operation Date Reception
321
Means of Transmitting Demand Date for Setting Transmitting Condition Information
Air Conditioner

Fig. 14

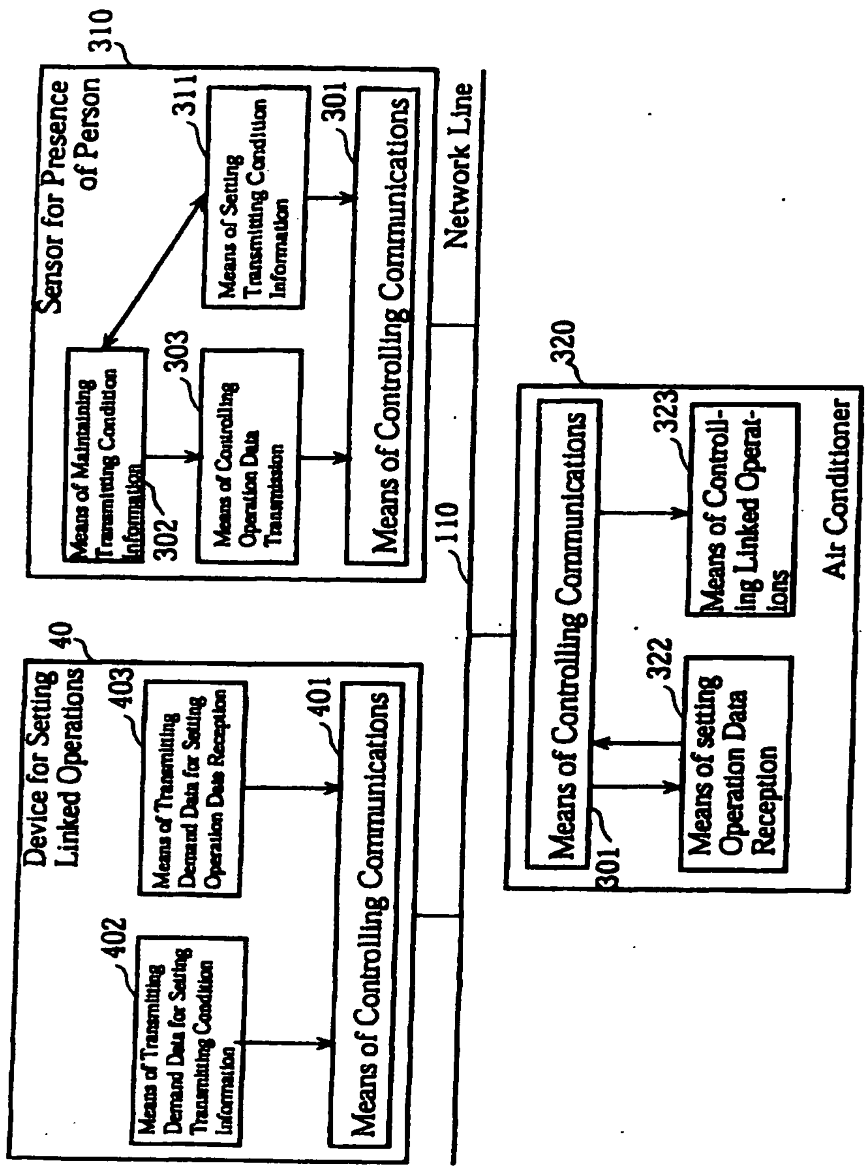
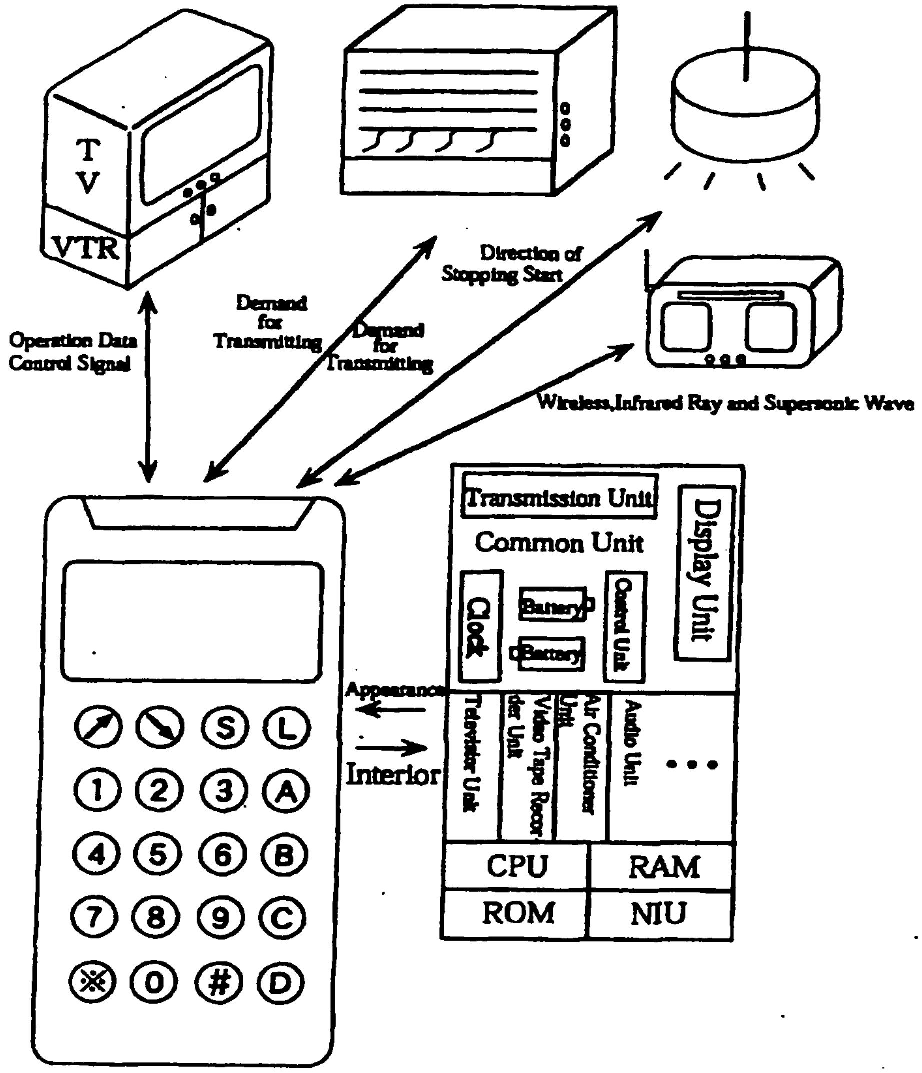

Sensor for Presence of Person
310
Means of Maintaining Transmitting Condition Information
302
Means of Controlling Operation Data Transmission
303
Means of Setting Transmitting Condition Information
311
Means of Controlling Communications
301
Network Line
110
Air Conditioner
320
Means of Controlling Communications
301
Means of setting Operation Data Reception
322
Means of Controll-ing Linked Operat-ions
323
Device for Setting Linked Operations
40
Means of Transmitting Demand Data for Setting Transmitting Condition Information
402
Means of Transmitting Demand Data for Setting Operation Data Reception
403
Means of Controlling Communications
401

Fig. 15


T
V
VTR
Operation Data
Control Signal
Demand
for
Transmitting
Demand
for
Transmitting
Direction of
Stopping Start
Wireless,Infrared Ray and Supersonic Wave
S L
1 2 3 A
4 5 6 B
7 8 9 C
※ 0 # D
Appearance
Interior
Transmission Unit
Common Unit
Clock
Battery
Battery
Control Unit
Display Unit
Television Unit
Video Tape Recorder Unit
Air Conditioner Unit
Audio Unit
• • •
CPU
RAM
ROM
NIU

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/04718

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] H04Q 9/00
H04L 12/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] H04Q 9/00
H04L 12/28

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
JICST FILE(JOIS), WPI(DIALOG)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Yasuji SAKAI, "Konsento kara Kaden Seigyo suru Shikoku Denryoku no "Open PLANET"; Kateinai no Denki haisen ga LAN ni Shinka", Nikkei Multimedia, No.33, (Nikkei BP K.K.), 15 March, 1998, pages.70-75	1-12
Y	Hiromi NAKAGAWA, "Arayuru Kiki wo Ichigen Setsuzoku; 100M Bit/Byou ga Shiya ni", Nikkei Communication, No.268, (Nikkei BP K.K.), 20 April, 1998, pages.138-147	1-12
Y	Junichi IETAKA, et al., "Internet wo Riyou shita Kakkitekina Denki Kiki no Enkaku Kanshi, Seigyo System", Denki Hyouron, Supplement issue, No.394 (Denki Hyouronsha), 30 June, 1998, pages.68-72	1-12
Y	"Denryoku Kaisha ga Taian suru Home Network Kousou", Computer & Network LAN, Vol.17, No.3 (Kabushiki Kaisha Ohmu), 01 March, 1999, pages.32-36	1-12
Y	EP, 0853401, A2 (SHARP K.K.), 31 December, 1997 (31.12.97) & JP, 10-257075, A2	1-12

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"P" document published prior to the international filing date but later than the priority date claimed
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 October, 2000 (24.10.00)	07 November, 2000 (07.11.00)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/04718

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	(Kaden no Renkei Seigyo no tameno Network Kousei)	
Y	JP, 10-094199, A (Toshiba Corporation), 10 April, 1998 (10.04.98) & US, 6018690, A (Kaden no Soudenryokuryou Seigyo no tameno Network)	1-12
A	Reiko UENO, et al., "HBS Tougou Network Jisshou System", National Technical Report, No.37, No.6, (Matsushita Electric Ind. Co., Ltd.), December, 1991, pages.687-694	1-12
A	BARRY HAASER, "Control networks extend energy management solutions", ELECTROTECHNOLOGY, Vol.7, No.1 (February/March 1996) pages.11-13	1-12
A	MAURY WRIGHT, "LOWCOST CONTROL LANs ADD AUTOMATION TO HOMES, AUTOS, AND OFFICES", EDN, Vol.37 No.15, July 20, 1992, pages.182-188	1-12

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

Handoff Support for Mobility with IP over Bluetooth

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Peter Martini[1], Markus Schetelig[2], Asko Vilavaara[3]

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Abstract

The BLUEPAC (BLUEtooth Public ACcess) concepts presented at LCN 1999 were ideas for enabling mobile Bluetooth devices to access local area networks in public areas, such as airports, train stations and super-markets. The proposed protocols support mobility on OSI layer 3. This paper concentrates on the necessary layer 2 protocol concepts for supporting mobility and handoffs between different access points. Furthermore, we present the necessary adaptations for allowing IP datagrams to be exchanged between the mobile Bluetooth devices and access points. The BLUEPAC protocol concepts have been implemented above a Bluetooth emulation system to test their feasibility. First results clearly showed the importance of minimizing the handoff duration to allow efficient operation of upper layer protocols such as TCP.

1. Introduction

In recent years, mobile communication has moved into the center of interest of many people. With the current development of mobile devices, making them smaller and more affordable for a wide range of end users, the use of cellular phones and messaging systems show a tremendous growth in popularity. Due to this overwhelming success of personal mobile communication, wireless technologies are more and more accessible for the area of mobile computing. Today, a large and ever increasing number of mobile computers and Personal Digital Assistants (PDA) are able to exchange data and to synchronize with other computing devices across wireless links.

For short range wireless communication, a large set of proprietary solutions already exists. However, incompatibility of these technologies often limits interoperability between devices of different classes or different manufacturers. To overcome this situation the Bluetooth short range radio standard is on its way to provide vendor independent wireless communication at low cost. This cheap but powerful technology will be available in a wide range of mobile devices. Thus, there will be an increasing demand to access IP based local computer networks to profit from locally available services as well as globally available services and information distributed by the Internet. One can imagine these accessible networks in home, office or public environments. This paper concentrates on public access environments, which we call BLUEPAC areas. In a BLUEPAC area, mobile Bluetooth devices should be able to move between different access points while still being addressable via the same IP address. Protocol concepts addressing this problem have already been presented in [1]. While the LCN 1999 presentation concentrated on mobility aspects on OSI layer 3, the present paper additionally considers layer 2 mobility.

The paper is structured as follows. Section 2 gives a short summary of the Bluetooth technology. In Section 3, public access scenarios are presented, which are then combined to form a reference network architecture. Then, the layer 3 protocols required for supporting mobility in BLUEPAC networks are summarized. Section 4 presents the IP Adaptation Layer which allows the exchange of IP datagrams between a Bluetooth device and an access point. Additionally, the handoff performance is discussed. Section 5 presents the Bluetooth emulation system which was used to test the feasibility of the BLUEPAC protocol

0-7695-0912-6/00 $10.00 © 2000 IEEE

concepts. Finally, section 6 presents our conclusions and describes future work.

2. Bluetooth overview

Bluetooth [2, 3] is a low-cost, low-power wireless networking technology designed to operate in a person's operating space, i.e. the space around a person that typically extends up to 10 meters in all directions. The Bluetooth radio transmission uses a slotted protocol with a FHSS (Frequency Hopping Spread Spectrum) technique in the globally available unlicensed 2.4 GHz ISM (Industrial, Scientific and Medical) band. The hop frequency is up to 1600 hops per second, the frequency spectrum is divided into 79 channels (or 23 in some countries) of 1 MHz bandwidth each. The frequency hopping scheme is combined with fast ARQ (Automatic Repeat Request), CRC (Cyclic Redundancy Check) and FEC (Forward Error Correction) to achieve appropriate reliability on the wireless link. Each device is identified by a globally unique 48-bit address derived from the IEEE 802 standard.

Communication between Bluetooth devices follows a strict master-slave scheme, i.e. there is no way for slave devices to communicate directly with each other. A device acting as master can have up to 7 active slaves connected. Master and slaves form a so-called *piconet*, in which the master defines the timing and the hop pattern. The slaves have to stay synchronized to the master while participating in the piconet.

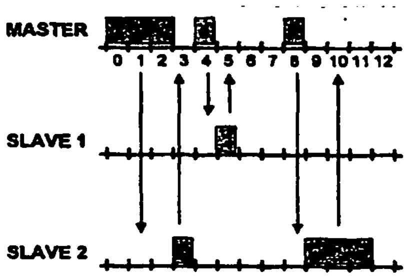

Figure 1: Time division duplex access scheme

Between master-slave pairs, both Synchronous Connection Oriented (SCO) links (typically used for voice) and an Asynchronous Connectionless link (ACL) are supported. For ACL links, Time Division Duplex (TDD) is used to control access to the slots that are not already reserved for SCO connections: The master may begin to send a packet in even numbered slots only. The slave addressed by this packet is the only device allowed to send in the odd numbered slot following the master's packets. To always keep up the alternation between even and odd slots, packets must occupy an odd number of slots. Consequently, Bluetooth defines different packet types with a length of 1, 3, or 5 slots. An example for the TDD medium access control is depicted in Figure 1. The piconet master sends a three slot packet to the second of its two slaves in the slots 0 to 2. The addressed slave may respond in the subsequent slot 3. In most cases, it will respond at least with a packet that acknowledges the master's transmission. In our example, the packet sent by the second slave occupies only one slot and the master is free to address slave 1 in slot 4. If the master does not use its transmission right like in slot 6, no slave is allowed to send in the subsequent odd numbered slot.

2.1. Finding and connecting to devices

As Bluetooth devices need to be synchronized while participating in a piconet, a procedure is required to establish the synchronization of two devices. This procedure is called *paging* and requires the device address of the device to connect to. If the device address is not known, an *inquiry* procedure is needed first to retrieve the address.

Any device that wants to accept connection attempts from a master periodically scans on one frequency out of a cycle that consists of 32 frequencies used for this purpose. These 32 frequencies depend on the device address of the particular device. The frequency used for a particular *page scan* depends on the internal clock of the device and changes every 1.28 seconds. Typically, the scan duration is 18 slots (the *page scan window*) and scans are separated by 1.28 seconds (the *page scan interval*).

A master that wants to connect to a slave with a known device address tries to hit the scan window of the slave by sending packets with the right frequency and access code. In most cases, the master will have a clock estimate for the slave device. Thus, the master is able to compute an estimate of the slave's scan frequency from the slave's device address and its clock estimate. To tolerate timing inaccuracies, the master does not use this frequency alone to reach the slave. Instead, it repeats sending a *page train* that consists of 16 frequencies situated around the estimated frequency. As the master does not know exactly when the slave schedules its page scan window, the page train has to be repeated for at least the duration of one page scan interval. If no response from the slave is received within this period, the master's clock estimate may have been too inaccurate to hit the scan frequency of the paged slave. Consequently, the master repeats another page train that consists of the remaining 16 frequencies out of the 32 paging frequencies of the slave. The master will alternate between the two page train repetitions until it connects to the paged device or a timeout occurs.

If the paged slave receives a packet from the master's page train during its page scan window, the timing of this packet is sufficient to achieve a coarse synchronization

between the two devices. Using this synchronization, the master sends a Frequency Hop Synchronization (FHS) packet to the slave, which allows the slave to properly synchronize with the master.

During connection setup, the paged device joins the piconet of the paging master as a slave. However, there are scenarios, where it is desirable that a paging device joins, as a slave, the piconet of the paged device. In this situation, a master/slave-switch should be initiated after connection setup, which passes the responsibility for a particular Baseband connection to the slave, transferring the former master into the paged device's piconet.

Bluetooth defines another procedure called *inquiry* that enables a device to discover which other devices are in range and to retrieve their device addresses and internal clock settings. For this purpose, each device that wants to be detectable periodically scans on one out of 32 inquiry frequencies, just like in the page scan mode already described. In contrast to the page scan frequencies, the frequencies used for inquiry do not depend on the address of the scanning device. In analogy to the paging, the device performing the inquiry will alternate between two page train repetitions containing 16 out of the 32 frequencies each. During these repetitions, it will collect incoming FHS packets from devices in range.

These FHS packets are sent if a device receives a packet of an inquiry train during its inquiry scan window. However, the responses are delayed by a random backoff time in order to reduce the probability of collisions if two or more devices scan on the same frequency. Additionally, the device may be configured to respond to inquiries for special devices only. If so, it scans for special access codes (DIACs – Dedicated Inquiry Access Codes) instead of scanning for the access code used during inquiry for all devices (GIAC – General Inquiry Access Code). Thus, a device that wants to restrict its inquiry to devices of a certain class (e.g. Base Stations), will use a DIAC reserved for this class during its page train repetitions.

After the inquiry procedure has been completed, a connection to one of the devices found may be established using the clock information learned during the inquiry procedure for paging.

2.2. Bluetooth protocol stack

This section gives a brief overview of the Bluetooth protocol stack, which is depicted in Figure 2. The Radio layer defines the physical characteristics of the RF link. The functionality of the Baseband layer has already been described at the beginning of section 2 and includes the TDD MAC, definition of SCO and ACL link, packet types, automatic retransmission, forward error correction and encryption.

The Link Manager Protocol (LMP) is responsible for managing link-setup and configuration of Bluetooth devices. This includes tasks such as master/slave-switches, control of power modes, managing authentication and encryption, etc. The Logical Link Control and Adaptation Protocol (L2CAP) provides connection-oriented and connectionless datagram services to upper layer protocols, including segmentation and reassembly (SAR) and protocol multiplexing. The RFCOMM protocol emulates a serial line to allow legacy applications or protocols to work over Bluetooth with no or little adaptation.

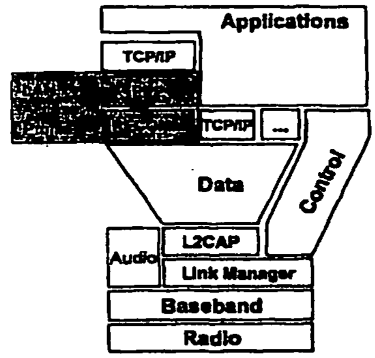

Figure 2: Bluetooth protocol stack

The Point-to-Point protocol (PPP, [4]) is an example of such a protocol. As most operating systems are able to do networking using PPP over a dialup connection or a null modem cable, using PPP over RFCOMM is the easiest way to incorporate support for TCP/IP or other network protocols into the Bluetooth protocol stack. In fact, this is the way Bluetooth LAN access is currently specified in [2], although more efficient solutions like running TCP/IP directly on top of L2CAP are possible. With BLUEPAC, we propose such a solution, which has the additional benefit of being able to support roaming devices.

3. Prior work on BLUEPAC

In this section, we describe the work that already has been done in the past for BLUEPAC networks. After giving an overview of the typical public access scenarios, a reference network architecture is presented which meets the requirements of all these scenarios. Finally, we describe the protocol concepts for supporting mobility.

3.1. Scenarios

The BLUEPAC protocol concepts cover all scenarios where a user with a Bluetooth device wants to get access to data and/or communication services within a public area. Examples for such scenarios are among others, super-markets, railway stations and airports. The available services in such a public area may vary from simple local information services (e.g. special offers in a super-market,

timetables at a railway station, ...) to services using a Gateway to access wide area networks (e.g. Internet, IP-telephony, ...).

A possible way to categorize public access scenarios is by dividing them into scenarios with low user mobility and scenarios with high user mobility. The scenarios with low user mobility include situations such as in a train or airplane, whereas scenarios with high user mobility may be imagined in train stations or super-markets. When considering the structure of the network architecture, it is more difficult to achieve acceptable performance in an area with high user mobility, in comparison to areas with low user mobility, cf. section 4.2.

3.2. Reference network architecture

The reference network architecture combines all of the public access scenarios given in the previous subsection. It is a general network architecture which is valid for all BLUEPAC scenarios.

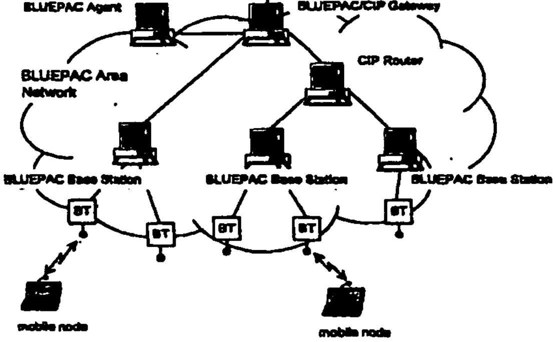

Figure 3: BLUEPAC reference network with functional elements

This architecture is depicted in Figure 3 and its elements are described in the following. The *BLUEPAC area network* is the fundamental part of the network, which is accessed by the *mobile Bluetooth nodes*. In most cases the BLUEPAC area network is a wired network. The *BLUEPAC Base Stations* are the access points. The mobile Bluetooth nodes use these Base Stations to gain access to the BLUEPAC area network. Thus, a Base Station consists of a wired network interface and at least one Bluetooth transceiver (BT). The *BLUEPAC Gateway* may connect the BLUEPAC area network with a public network (e.g. Internet) providing access to global information services. The *BLUEPAC Agent* co-ordinates the communication with arriving mobile nodes. This includes tasks such as the assignment of IP addresses. Location-based information services may be provided by an *Application Server* connected to the BLUEPAC Gateway. Finally, the *Cellular IP (CIP) Routers* play an important role in BLUEPAC networks. They are responsible for the routing to and from mobile nodes. They also allow mobile devices to move between different Base Stations while keeping existing higher layer connections alive.

3.3. Mobility support

In most BLUEPAC scenarios, the Bluetooth devices accessing the network will be in motion. A layer 3 solution for offering mobility support in BLUEPAC networks by adapting Mobile IP and Cellular IP has been presented in [1] and shall only be summarized here. The layer 2 requirements for supporting mobility in BLUEPAC networks are presented in the subsequent section.

Cellular IP (cf. [5]) is a protocol that allows routing of regular IP datagrams to moving mobile hosts in local networks. It introduces functionality for fast route updates enabling mobile devices to change their point of attachment frequently. The common IP routing technique which employs subnet masks assumes its network nodes to be statically attached to the network. Fast changes between different Base Stations would result in severe routing problems and the need of using an IP address dependent on the subnet the mobile Bluetooth device is connected to.

The Cellular IP protocol has to run on mobile Bluetooth devices, the Base Stations, the Routers between Base Stations and Gateway, and the Gateway. The Cellular IP protocol notices all IP datagrams sent by the mobile device, and maps its source IP address to the interface the datagram was received from. This mapping is stored in a cache. Hence, datagrams addressed to this IP address may then be forwarded by looking up which interface leads to the mobile device.

If the mobile device does not have anything to send for some time, then it has to send control packets to refresh the cache entries in the nodes. For scalability reasons and performance reasons two different caches are used – the *route cache* and the *paging cache*. The route cache entries tell the location of active mobile devices, whereas the paging cache stores the location of inactive devices. Entries in the route cache have only a very short lifetime, whereas entries in the paging cache exist longer before they are erased from the cache.

Cellular IP solves the micro mobility problem within BLUEPAC networks. However, in some cases macro mobility may be required. For this purpose, Mobile IP (cf. [6]) may be applied. If a mobile Bluetooth device wants to use Mobile IP in a BLUEPAC network, it needs a home network with a home agent. Furthermore, Mobile IP's Foreign Agent has to be located at the Cellular IP Gateway, as described in [5].

3.4. Auto-configuration of mobile devices

BLUEPAC networks are public access networks that should offer unconstrained access for all kinds of mobile Bluetooth devices. Several cases have to be considered: One case is that a Bluetooth device entering a BLUEPAC network has its own IP address and wants to use this address in the BLUEPAC network. If the BLUEPAC network supports Mobile IP, the mobile Bluetooth device may want to contact its home agent to maintain accessibility with its own IP address. A different case is that a mobile Bluetooth device does not have its own IP address and requires the assignment of such an address. Consequently, a mechanism is needed which allocates an IP address and assigns this to the associated device. As Cellular IP routing does not require IP addresses to contain location dependent information such as subnet addresses, there are no constraints for the IP addresses to be assigned, except that they must be assigned uniquely within the BLUEPAC area network. Moreover, a mechanism is needed which provides these entities with information relevant for the connection to the BLUEPAC network, like Domain Name Server, Proxy Server, Mail Server and more.

The Dynamic Host Configuration Protocol (DHCP) is well suited to accomplish this task, as it is able to dynamically assign addresses to hosts and ensure unique addresses. Furthermore, it may grant addresses only for a limited duration in order to reuse addresses of mobile nodes that left the network without releasing their addresses. Apart from address assignment, DHCP may be used to transport other configuration parameters like the ones mentioned above, as well.

Downstream routing of datagrams performed by Cellular IP is only based on IP source addresses from upstream packets. This raises a chicken/egg issue when trying to use Cellular IP with IP address autoconfiguration. A mobile node is not able to install a valid path pointing to the device without having a valid IP address, but without a valid path the DHCP server is not able to reach the mobile device to assign an IP address to it. One could use the link layer address of a mobile node to deliver packets that assign IP addresses, but these are only known on the last link, i.e. the Bluetooth link. However, DHCP servers can not simply be placed on each Base Station, since mobile nodes should retain their assigned address independently from their current Base Station. Thus, central coordination is required to ensure unique addresses in the whole network.

Fortunately, the Bootstrap Protocol ([7], [8]), the protocol on which DHCP is based, allows the use of BOOTP relays, which forwards all BOOTP or DHCP messages to a server. Using relays, it is easy to avoid assigning duplicate addresses by installing a central DHCP server in a BLUEPAC Area (see Figure 4).

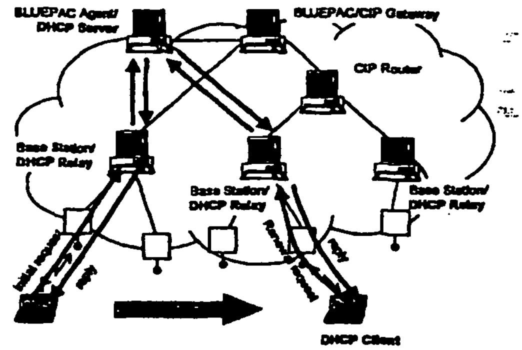

Figure 4: DHCP lease renewal

The Base Stations act as DHCP relays and do not perform any real DHCP transactions; they just relay DHCP messages between mobile nodes and the DHCP server installed on the BLUEPAC Agent. As already mentioned, address leases obtained from the DHCP server have a limited duration. If a mobile node wants to retain its assigned IP address, it will have to renew its lease before it times out. This can be done using any relay, since the central DHCP server manages the old lease and will send the response to the proper relay.

4. Handoff support

This section describes and evaluates the layer 2 concepts which are required to support mobility of Bluetooth devices in a BLUEPAC network. We focus on the IP Adaptation Layer which is inserted between IP and L2CAP to provide a suitable data link layer by hiding Bluetooth specific details from IP.

4.1. IP Adaptation Layer

In most BLUEPAC scenarios, mobility must be taken care of. Thus, our protocol concepts focus on enabling Bluetooth devices to migrate between different Base Stations while maintaining existing connections to hosts within or outside of the BLUEPAC network. The layer 3 protocols necessary for supporting this feature have already been presented in [1] and summarized in the previous section. Now, we study the requirements for supporting handoffs on layer 2. The Bluetooth piconet design is discussed and the IP Adaptation Layer is presented which is needed for the exchange of IP datagrams between a mobile Bluetooth device and an access point such as a Base Station in a BLUEPAC network.

There are two fundamental approaches to the basic piconet design in a BLUEPAC network. Firstly, the Base Station may act as a Bluetooth slave and the mobile Bluetooth devices are the masters. Hence, each mobile device

establishes an own piconet with the Base Station as slave. This approach is shown in the right half of Figure 5. The advantage of this design is that approaching mobile devices wishing to find a new Base Station simply have to start an inquiry procedure and page procedure. The inquiry procedure is necessary for finding the Bluetooth device address of the Base Station, after which the mobile device can use the page procedure for a definite connection to the Base Station. Therefore, the Base Station has to periodically enter the page scan and inquiry scan modes to respond to approaching mobile devices. However, the disadvantage of this piconet design is that the Base Station has to take part simultaneously in several piconets. Thus, a Time-Division-Multiplexing scheme has to be applied by the Base Station in order to be addressable in all of the piconets. These time consuming switches among the different unsynchronized mobile device's piconets result in considerable performance degradations.

In the second piconet design approach, the Base Station acts as the master and the connected mobile Bluetooth devices are slaves of the Base Station's piconet. An example is shown in the left half of Figure 5. As Bluetooth slaves are only allowed to send after being addressed by the master, this approach allows the Base Station to control the medium access and the amount of data sent by the mobile devices.

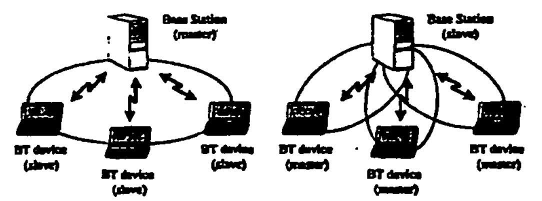

Figure 5: Comparison of a Base Station acting as master and as slave

A Bluetooth piconet is restricted to a maximum of seven active slaves which is a serious limitation for BLUEPAC networks. This may be avoided by connecting several Bluetooth transceivers with overlapping range to the Base Station. Each added transceiver enables the Base Station to create an additional piconet with up to seven slaves.

The main disadvantage of this piconet design with Base Stations acting as masters is that mobile Bluetooth devices wanting to connect to the BLUEPAC network have to wait for the master, i.e. the Base Station, to initiate an inquiry and page procedure. These procedures take a substantial amount of time and during this time none of the already connected devices is able to send or receive any data via the Base Station. To prevent this from happening and to gain from the advantages of both piconet designs, a combination of both approaches is suggested for using in BLUEPAC networks. This approach is presented in the following.

The Base Station acts as master and can have up to seven Bluetooth devices as slaves with each installed Bluetooth transceiver. New approaching Bluetooth devices use the inquiry procedure and a dedicated inquiry access code for Base Stations to detect the Bluetooth device address of one of the Base Station's Bluetooth transceivers. For the definite connection to the Base Station, the mobile device uses the received device address in the paging procedure. Thus, the Base Station has to periodically enter inquiry scan mode and page scan mode to respond to approaching mobile devices. After connecting to the Base Station, the mobile device is master and the Base Station is a slave in the mobile device's piconet. At the same time the Base Station is the master of the piconet with previously connected Bluetooth devices. Now, a master/slave-switch occurs directly after the mobile device connects to the Base Station. Hence, the new Bluetooth device is added to the existing piconet as a slave.

As it is likely that connected Bluetooth devices are mobile, it is possible for them to leave the range of the Base Station they are connected to and enter the range of a new Base Station. Here, methods are necessary for detecting the loss of connectivity to the first Base Station. As soon as the loss of connectivity is detected, a connection to the next available Base Station must be established. The Bluetooth LAN access profile defined in [2] may offer means for IP access to local area networks. However, it lacks the mobility described above and can not be adapted easily to the BLUEPAC protocol concepts. To abolish this deficiency, the following introduces the IP Adaptation Layer which is inserted between IP and L2CAP. For upper layer protocols, the IP Adaptation Layer behaves like a network interface, which is able to receive and send IP datagrams. Hiding Bluetooth specific details from upper layer protocols, the IP Adaptation Layer uses L2CAP and accesses the Bluetooth link layer directly by means of the LMP.

When comparing the IP Adaptation Layer on the mobile device and on the Base Station, they differ in some aspects. In the following, both versions of the IP Adaptation Layer are presented.

IP Adaptation Layer for mobile devices

The state machine of the IP Adaptation Layer for mobile devices has three major states: *Discovery*, *Configuration* and *Connected*. These three states and the corresponding transitions are depicted in Figure 6.

The mobile Bluetooth device is in the *Discovery* state after its initial start-up. The task of the *Discovery* state is to find the nearest Base Station.

In general, the mobile device does not know anything about available Base Stations. Therefore, the inquiry procedure has to be initiated to find an available Base

Station within range. For this, a dedicated inquiry access code should be reserved to guarantee that only Bluetooth device addresses from Base Stations are obtained. The inquiry procedure may terminate as soon as the first Base Station is found. If no Base Station is found, the inquiry procedure needs to be repeated.

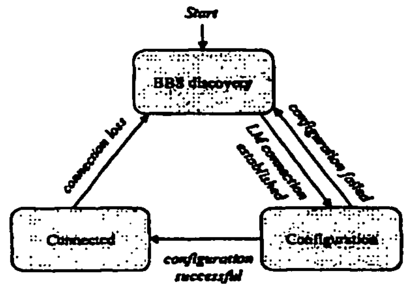

Figure 6: State machine for the IP Adaptation Layer for mobile devices

After a Base Station's Bluetooth device address has been provided to the mobile device, the IP Adaptation Layer initiates a page procedure in order to establish a connection to this Base Station. Subsequently, the state machine of the IP Adaptation Layer changes to the state *Configuration*.

Here, the first step that the mobile device has to expect, is a master/slave-switch initiated by the Base Station. The mobile device should then initiate a connection-oriented, bi-directional L2CAP channel on the existing Baseband connection, which will be used for the actual delivery of IP datagrams.

Before the transmission of IP datagrams starts, the MTU of the L2CAP datagram payload has to be negotiated. This is done after the connection has been established, which is employed by the corresponding L2CAP connection request/response signaling messages. The Base Station sends a configuration request message containing the size of the MTU accepted by the Base Station. This value must be confirmed by the mobile device in a response message. The next step is the negotiation of the MTU size accepted by the mobile device. For this, the mobile device sends a configuration request message containing the MTU size for incoming datagrams. For simplicity, the value should be equal to the one previously suggested by the Base Station.

As soon as the mobile Bluetooth device receives a confirmation through the corresponding response message it transits to the *Connected* state. However, if an error occurs during the configuration, existing Baseband and L2CAP connections are released immediately and the device returns to the *Discovery* state.

If a mobile device reaches the *Connected* state for the first time, an IP address assignment may be necessary. This may be done by existing network configuration protocols such as DHCP (see section 3.4). Additionally, devices must be allowed to use their own IP addresses in the BLUEPAC network, if Mobile IP is available. This aspect has already been addressed in section 3.3.

Another important job for the IP Adaptation Layer for mobile devices is to detect a possible handoff by broken link detection. The Bluetooth specification provides the *Link supervision timer* for detecting broken links. The timer is set to an initial value and is then reset with every received packet. If the timer expires, an event is generated notifying about the link timeout. As the *Link supervision timer* resides on the link layer, it is an ideal mechanism for detecting broken links. However, the default value specified for the *Link supervision timer* is 20 seconds. This value is far too large for efficient handoffs in a BLUEPAC network. An appropriate value has to be selected very carefully. A too small value has the effect of tearing down a connection too early and thus wasting time for reconnecting with an inquiry and page procedure. A too large value has the affect that time is wasted by regarding a link as alive, despite being out of range of the Base Station.

IP Adaptation Layer for Base Station

For Base Stations, the IP Adaptation Layer is somewhat simpler than for mobile devices. Its main task is to maintain the connections of the connected mobile Bluetooth devices. The state machine for each active connection to a mobile host has two states, the *Configuration* state and the *Connected* state. The state transition diagram is depicted in Figure 7.

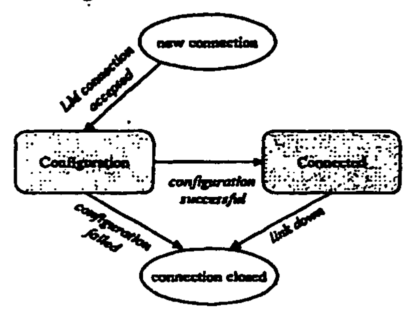

Figure 7: State machine for the IP Adaptation Layer for Base Stations

In order to detect new mobile Bluetooth devices trying to connect to the BLUEPAC network, the Base Station has to perform periodical page scans and inquiry scans on each installed transceiver, unless the maximum number of devices for the respective piconet has been reached. If the Base Station receives packets addressed to the dedicated inquiry access code for Base Stations while performing the inquiry procedure, it should respond and inform the

inquiring device about its Bluetooth device address. After a new Baseband connection has been accepted, the IP Adaptation layer transits to the state *Configuration*.

Similar to the IP Adaptation Layer for mobile devices, the *Configuration* state is responsible for configuring the established connection to the mobile device appropriate for the BLUEPAC network. As during normal operation the Base Station should be master of each connection it maintains, the first step is a master-slave switch. Thus, the Base Station is responsible for initiating this master/slave-switch directly after accepting a connection from a slave. Subsequently, the L2CAP channel has to be created and configured. The L2CAP channel configuration is started by the Base Station. The crucial part of the L2CAP configuration is the negotiation of the MTU size already described above. After a successful negotiation of the L2CAP configuration, the *Connected* state is entered.

For each connected Bluetooth device in the *Connected* state, a Base Station must maintain a data record of the form *(I, A, B)*, where *I* is the connection identifier given by L2CAP, *A* is the IP address of the mobile Bluetooth device, and *B* is its Bluetooth device address. The IP address is taken from the source field of the first non-broadcast and non-multicast IP datagram that is received from the mobile Bluetooth device. The Bluetooth device address is known from the paging procedure and is used to deliver DHCP replies to the proper device prior to the IP address assignment.

IP datagrams received by the Base Station and coming from a mobile device, must be passed by the Base Station's IP Adaptation Layer to the upper layer, which is Cellular IP in case of the BLUEPAC network. The IP datagrams received by the Base Station and coming from the network, that is to say, the IP datagrams passed down from the Cellular IP layer to the IP Adaptation Layer, must be forwarded via the corresponding L2CAP channel to the addressed mobile Bluetooth device. The L2CAP channel identifier may be found by looking up the destination IP address in the data records.

The Base Station must also perform broken link detection by using the link supervision timer. As soon as a broken link is detected, the Baseband connection is terminated and the Base Station immediately de-allocates the corresponding mapping in the data records. In contrast to the mobile device, the Base Station should not attempt to reconnect to a lost mobile Bluetooth device.

4.2. Analysis of handoff performance

In our design of BLUEPAC, we only rely on standard Bluetooth features like inquiry or paging procedures to perform handoffs between Base Stations. As Bluetooth was not designed as a cellular system with fast and seamless handoff, we can not expect the proposed handoff procedure to be adequate for applications that depend on hard QoS guarantees such as voice communication. However, the duration of link loss must be acceptable for classical data communication. In the following, we give an estimate of the duration of disconnection caused by a handoff. For our analysis, we split the handoff duration into three phases: detection of link loss to the current Base Station by the link supervision timer, inquiry for a Base Station in range and paging to synchronize with the chosen Base Station.

As the mobile node learns about the native Bluetooth clock of the upcoming Base Station by receiving an FHS packet during inquiry, the subsequent paging will succeed with the first page train. Furthermore, we assume that the Base Stations perform page scan immediately after an inquiry scan. This is also suggested in [2]. Therefore, we do not include the duration of paging in our analysis as paging succeeds very quickly after inquiry.

In our estimation of the inquiry time, we need to consider that multiple Base Stations may be in range of a mobile node. This is very likely in areas with a high density of mobile devices such as waiting areas or at a IETF meeting. Without further measures a Base Station can serve up to seven mobile nodes due to the restriction of seven active slaves in a piconet. A piconet can contain additional inactive members in park mode (a power saving mode), but this would require continuous swapping of devices in and out of park mode.

As we want to connect to a single Base Station, inquiry is terminated as soon as the first response from a Base Station is received. We assume that the Base Stations are not synchronized in any way, i.e. they perform their inquiry scan independently. Furthermore, the model does not account for transmission errors or collisions, as we expect only a few responses when using a dedicated inquiry access code.

By T_{SI} we denote the interval between two scan windows of a Base Station (typically 1.28 s) in which it scans for inquiring devices. T_{IT} is the duration of one inquiry train (typically 2.56 s), and T_{MaxRB} is the maximum backoff time (0.64 s).

If the first train of the inquiring device succeeds, a Base Station responds as soon as it schedules its inquiry scan window for the first time after the train has started. Thus, the response time is uniformly distributed between 0 and T_{SI}. In the following we represent this time by the random variable $X \sim U(0,T_{SI})$. We have to add the Base Station's random backoff time, which is represented by the random variable $Y \sim U(0,T_{MaxRB})$. Because it does not add much delay, we ignore the fact that the random backoff does not necessarily begin at the start of the scan window, but can begin anywhere within the scan window, which has a typical length of approx. 11 msec. Similarly, there is an additional delay of up to the duration of one

page train (approx. 10 msec) after the slave device returns from random backoff.

Furthermore, we do not consider the situation in which the inquiring device changes its page train during the backoff period in such a way that the frequencies do not match anymore (probability for this is approx. 1/64). If this happens, this particular Base Station will not respond to the current train, but to the repetition of the train (during inquiry, the master switches repeatedly between the two trains).

Given these assumptions, if k Base Stations respond to the first page train, the cumulative distribution function (cdf) for the first answer in the first train is given by:

$$P(Z_{1,k} \le t) = 1 - \left(1 - P(X + Y \le t)\right)^k$$

Base Stations responding to the second train basically have the same cdf, they just have to wait for T_{IT} seconds until the inquiring device begins its second train:

$$P(Z_{2,k} \le t) = P(Z_{1,k} \le t - T_{IT})$$

Let's suppose we have n Base Stations in range with k reacting to the first train and $n-k$ to the second one. If k is not zero, the distribution of inquiry durations is solely dependent of $Z_{1,k}$, because $T_{SI} + T_{MaxRB}$ is less than T_{IT}, i.e. the mobile node gets a response from one of the k Base Stations during its first page train and halts the inquiry procedure before beginning its second train. Otherwise (k=0), all Base Stations respond during the second train, i.e. the duration is only dependent on $Z_{2,n}$.

Whether a Base Station responds to the first or to the second page train of the mobile node depends on the clock offsets of the two entities. Since Base Stations and mobile nodes are not synchronized, both cases occur with the same probability. Furthermore, the train to which a Base Station responds remains fixed throughout the whole inquiry procedure, as the clock offsets may be assumed to be constant during the inquiry procedure, i.e. clock drift can be ignored. Thus, the response behavior may be described as an n-level Bernoulli trial and, using the cdfs given above, we obtain the distribution of response time for one to three Base Stations in range as shown in Figure 8.

If one Base Station is in range, there is a chance of 50% to get a response on the first page train (i.e. within $T_{SI} + T_{MaxRB}$ = 1.92 s); the average response time is approx. 2.2 seconds. With two Base Stations the chance to get a response within the first page train raises to 75%, as the probability of both Base Stations responding only to the second page train is only 25%. In this case, the average response time drops to 1.5 seconds. Finally, with three Base Stations, the probability raises to 87.5% and the average duration of inquiry drops to 1.1 seconds. Thus, with a well balanced value of the link supervision timer, handoffs are achieved within a few seconds most of the time, even if only one base station is in range. Adding more Base Stations significantly increases the probability to find a new Base Station within 2 seconds.

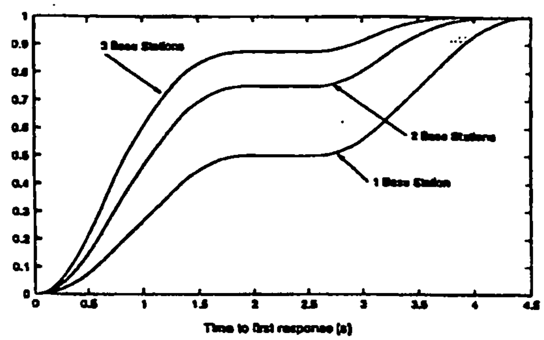

Figure 8: Cumulative distribution functions of inquiry response time for default values of T_{SI}, T_{IT}, and T_{MaxRB}

However, the disconnection duration experienced by users or applications may be much longer than the real duration of link loss, because of interactions with higher layer protocols. In particular, TCP's exponential backoff algorithm for retransmission attempts may cause additional delays after the connection has been re-established. The measurement shown in Figure 9 demonstrates this effect. It was made using the prototype described in section 5 and shows the throughput of a single TCP connection with two handoffs with a deliberately long duration. The handoffs were performed manually by disconnecting the mobile node from its current Base Station and reconnecting it after some time to the new Base Station.

The first handoff begins at about 20 seconds after the start of the measurement. From this point on, no data can be transmitted from the mobile node to the initial Base Station. The connection to the second Base Station was established shortly after the detection of the broken link (which was set to happen after approx. 8 seconds in this example and is marked by the first vertical dotted line in the figure). Within less than five seconds the Bluetooth connection to the new Base Station was established (the second vertical dotted line). As shown in the figure, it takes a while before data is transmitted again.

To analyze this behavior of TCP, a handoff was repeated but this time with a longer waiting time before reconnecting the mobile node to the Base Station. The second handoff starts at approximately 71 seconds. Once again the broken link is detected after eight seconds, which is depicted through the third vertical dotted line in the figure. This time, the mobile node was reconnected a bit later than before. After the Bluetooth connection to the Base Station has been re-established at 100 seconds (depicted by the fourth vertical dotted line), it takes even

longer for TCP to start sending data. Even though the connection has been re-established, TCP needs more than 20 seconds before sending the first data.

To explain this behavior, we need to know that the TCP connection does not recover until TCP sends its first retransmission after re-establishment of the link. Unfortunately, TCP doubles its retransmission timer after each unsuccessful retransmission event (exponential backoff). In the worst case, the additional waiting time may exceed the real disconnection time: Suppose we have a initial retransmission timeout of T_{init} and TCP has made n unsuccessful retransmission attempts. Hence, TCP waits $2^n T_{init}$ until the next attempt is made. The overall waiting time for n unsuccessful retransmissions sums up to

$$T_{init}(2^0 + 2^1 + \cdots + 2^{n-1}) = 2^n T_{init} - T_{init}$$

Thus, if the link comes up shortly after the n^{th} unsuccessful retransmission, the time until the TCP connection recovers will be even longer than the link outage.

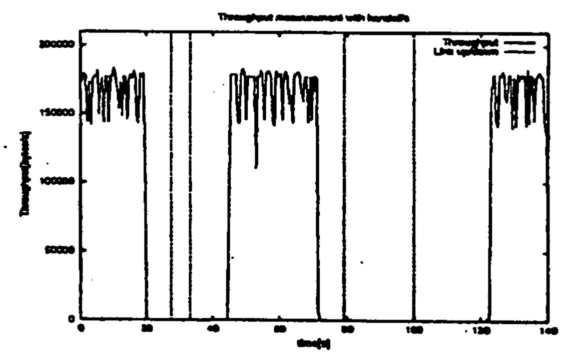

Figure 9: TCP throughput measurement in the BLUEPAC emulation system

Typically, the maximum retransmission timeout for TCP is restricted to approx. 1 minute. Thus, the additional inactivity may be up to one minute after reconnecting to a BLUEPAC Area if the disconnection lasts long enough to reach the upper limit of the retransmission timeout. If several disconnections occur in a row, the effect can even be more severe if all of TCP's retransmission attempts fall exactly into disconnection periods ([9]). We discuss possible solutions to these problems in the next section.

4.3. Optimizing handoff performance

Cellular IP supports a feature called semi soft-handoff, in which a mobile node in reach of several Base Station can initiate delivery of each datagram via all Base Stations in range of the mobile node to avoid packet losses during handoffs. As it should be clear by now, mobile nodes can not receive anything from a Base Station without prior synchronization using the page procedure. Furthermore, being connected to several Base Stations requires synchronization with several piconet masters by periodically switching between them. To avoid the complexity of piconet switches and costly synchronization procedures, the IP Adaptation layer was designed to hold up a single connection and to synchronize to a new Base Station only if the connection to the previous Base Stations is lost.

Therefore, the semi-soft handoff scheme does not alleviate the effects caused by the BLUEPAC handoff procedure, which were discussed in the last section. Adapting other approaches look more promising: Brown and Singh [9] address the effects on TCP connections caused by periods of disconnection by proposing a scheme called M-TCP, in which the sender is forced into *persistent* mode by manipulating the size of the advertised window. In this mode, no retransmission attempts occur, which prevents exponential backoff from occurring at all. Unfortunately, this solution is restricted to TCP connections and does not prevent packets from other protocols to be lost. Additionally, it requires a modified TCP implementation on the mobile node and increases complexity of the mobility management solution by requiring an additional entity in the communication path, which manages status information for each TCP connection.

Another, much simpler, approach that alleviates the impact of link loss considerably is called smooth-handoff ([10], [11]). It tries to prevent packet loss by buffering all packets recently sent to a mobile node. After a handoff, the stored packets and newly arriving packets are transferred from the former point of attachment to the new one, until the routing is adapted to properly reflect the new point of attachment. Thus, there is no packet loss, if the buffer size is sufficient to store all incoming packets during the link loss.

If buffer dimensioning considers the maximal handoff duration and a particular handoff completes very quickly, a large amount of duplicate packets will be unnecessarily sent over the air interface and may even cause TCP to slow down [11]. Interestingly, the reliable link layer of Bluetooth virtually eliminates the problems of duplicated packets, as the Base Station may remove packets from its buffer that were successfully received by a mobile node (i.e. acknowledged on Baseband layer). Only the last packet sent before disconnection may be duplicated if the Base Station was not able to receive the acknowledgement anymore.

Although the smooth handoff scheme does not prevent TCP from retransmitting packets during disconnection and from closing its congestion window, it will restart packet flow directly after delivery of the buffered packets to the mobile node.

5. Prototyping

This section briefly describes the structure of the Bluetooth emulation system which was used to test the BLUEPAC protocol concepts specified in the previous sections.

5.1. Emulation system

When we designed the BLUEPAC protocol concepts, there was no real Bluetooth hardware to test their feasibility. Hence, a Bluetooth emulation system was needed that could emulate Bluetooth's key properties. The emulation system we implemented runs on ordinary Linux PCs. Instead of communicating over a radio interface, they communicate via an emulated Bluetooth link running over an Ethernet connection. For this, we specified and implemented the Bluetooth emulation system in SDL/PR 88.

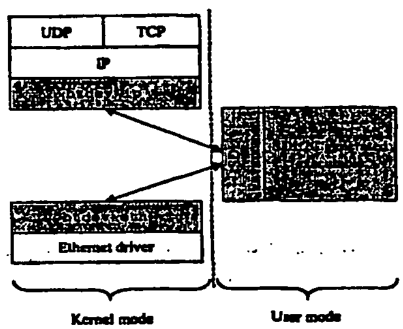

Figure 10 Integration of the emulation system into the TCP/IP protocol stack

SDL (Specification and Description Language) is a general purpose description language for communication systems and has been recommended by the ITU as a specification language of communication protocols (cf. [12]). To generate an executable process from the specified Bluetooth system, the tool *SDL2C* was used. SDL2C is a proprietary tool which was developed by the research group headed by Peter Martini at the University of Bonn. It is able to compile a given SDL/PR 88 source code into C source code. For the integration of this executable into the Linux TCP/IP stack, a loadable module, *btdev*, has been written, which is able to redirect the datagram flow on the hosting workstation between IP and the network interface through the emulation system.

The module *btdev* places itself between IP and the network interface and intercepts layer 2 frames sent by the local IP stack or received by any of the attached Ethernet network interfaces. These intercepted frames are stored into two separate queues, one for outgoing frames from IP (`btdev_ip`) and one for intercepted frames from the network interface (`btdev_eth`).

Figure 10 summarizes the interaction between the components of the emulation system and the existing kernel protocol implementation.

For IP the functionality behind *btdev* is transparent and it works just like an ordinary network interface driver. Thus, by providing routing entries for different destination hosts or network IP addresses, the choice which datagrams should be intercepted by *btdev* can be configured in a very flexible way.

5.2. Properties of the emulation

To test the implementation of the BLUEPAC protocol concepts, the Bluetooth emulation must emulate the core features provided by Bluetooth. In the following, we present the properties of the implemented Bluetooth emulation to show in what way the emulation differs or coincides with real Bluetooth.

Instead of a radio interface, our emulation system uses a 10BaseT Ethernet to emulate a Bluetooth piconet. Therefore, Ethernet broadcast frames with an unassigned protocol ID are exchanged with the Ethernet network interface driver. The PDU format in the Ethernet frame payload is close to the Baseband PDU format as given in the Bluetooth specification.

The most important Baseband properties have been implemented. A master-slave architecture with master- and slave slots at a single hopping frequency is emulated. The slot lengths have been increased drastically due to the danger of timing inaccuracy. Bluetooth's complex frequency hopping structure has not been considered in the emulation system. Thus, all Baseband packets occupy only one slot. Because of this new hopping channel environment, the Baseband inquiry and paging procedures had to be slightly simplified.

As the BLUEPAC protocol concepts do not need SCO links for LAN access, these have been omitted in the emulation system. Only ACL links have been considered.

A simplified Link Manager Layer is used, which supports connection establishment, connection release and the master/slave-switch. Other Link Manager functionalities such as authentication and aspects of QoS are not included.

Finally, the L2CAP has been omitted as the only functionality needed is the protocol multiplexing. Instead, the protocol ID for the payload of the Baseband packets is stored in a dummy L2CAP header preceding the actual payload. Furthermore, there is no need for L2CAP's fragmentation. For simplicity the Baseband packets can contain data up to 1024 octets. This value is reported as well as the MTU of the Bluetooth device and thus considered by TCP when generating IP datagrams. For UDP

datagrams exceeding the MTU, IP itself performs fragmentation.

5.3. Prototyping results

The objective of the Bluetooth emulation system was to test the feasibility of the BLUEPAC protocol concepts. Thus, on top of the emulation system, Cellular IP and the IP Adaptation Layer had to be implemented.

In order to test the feasibility and the performance of the specified protocol concepts, several different scenarios have been emulated. The prototyping system showed that Bluetooth devices are able to successfully move between different Base Stations and keep existing higher layer connections alive.

In addition, the tests have also shown the expected importance of keeping the reconnection time after a handoff low. Several TCP measurements have been done emphasizing this problem, which has been shown in section 4.2 (Figure 9).

Conclusively, the experiences and results of the prototyping system showed that all goals set for the BLUEPAC protocols have been achieved through successful specification and implementation of the protocol concepts.

6. Conclusions and further work

The BLUEPAC protocol concepts presented in [1] provided means for micro mobility and macro mobility support in BLUEPAC networks by using Cellular IP and Mobile IP, two protocols that reside on OSI layer 3.

This paper introduced the IP Adaptation Layer which solves the mobility and handoff problems on layer 2. It is responsible for keeping mobile Bluetooth devices constantly connected to one of the available Base Stations within range and thus provides an alternative to Bluetooth's LAN access profile which does not take mobility into account.

First results obtained from our Bluetooth emulation system testing the BLUEPAC protocol concepts have proven the necessity of enhancing the handoff performance which is strongly dependent on the time required by the broken link detection and Bluetooth's paging and inquiry procedures. Two different approaches in optimizing the handoff performance on the link layer have been investigated, the semi-soft handoff scheme and the smooth-handoff scheme. The smooth-handoff approach is promising when combined with an optimized value for the link supervision timer for enhancing the handoff performance. An ideal value for the link supervision timer is still an open issue. Therefore, it will be examined in future work with real Bluetooth hardware.

As soon as the first Bluetooth hardware becomes available, the BLUEPAC protocol concepts including Cellular IP, Mobile IP and the IP Adaptation Layer will be tested to verify the results given by the Bluetooth emulation system.

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